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National Sedimentation Laboratory

Oxford, Mississippi 38655

Interim Report

Evaluation of ARS and SCS Constructed Wetland/Animal Waste Treatment Project at Hernando, Mississippi In Cooperation with the Mississippi Soil Conservation Service 1991-1992

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EVALUATION OF ARS AND SCS CONSTRUCTED WETLAND/ANIMAL WASTE TREATMENT PROJECT AT HERNANDO, MISSISSIPPI[1]

INTERIM REPORT
1991-1992

A portion of the Demonstration Erosion Control Project (DEC) in the Yazoo Basin

by

Water Quality/Ecology & Watershed Processes Units
National Sedimentation Laboratory
Agricultural Research Service
U. S. Department of Agriculture
Oxford, Mississippi

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EXECUTIVE SUMMARY

A constructed wetland was implemented for treatment of dairy farm wastewater in DeSoto County, Mississippi during 1990. By agreement, the Mississippi Soil Conservation Service (SCS) designed and constructed a 135'x170' lagoon and three individually fed 20'x80' wetland cells. The Agricultural Research Service (ARS) evaluated cell processing efficiency of contaminants derived from milking equipment and tank cleanings, milking barn washings, loading area runoff, and rainfall. The wetland cells were planted in bulrush (*Scirpus validus*) immediately following construction; however, insufficient rainfall runoff prevented system functioning until April, 1991. Following system initialization, eighteen parameters were monitored at biweekly intervals (lagoon depth, rainfall, temperature, conductivity, dissolved oxygen, pH, oxidation-reduction potential, cell inflow and outflow, total solids, suspended solids, dissolved solids, chlorophyll, filterable ortho-phosphorus, total phosphorus, nitrate, ammonia, carbonaceous biochemical oxygen demand, and coliform bacteria). Chemical oxygen demand was measured quarterly.

This report provides an overview of project history, summaries of measured environmental and water quality parameters, and results and limited discussion for the eighteen month period from May, 1991 to November, 1992. Greatest reductions were measured for coliform bacteria (96%), ammonia (91%), chlorophyll (77%), and, to a lesser degree, for carbonaceous biochemical and chemical oxygen demand (65-70%), suspended solids (60%), and total and filterable ortho-phosphorus (70 and 57%, respectively). Use of catwalks at 1/4, 1/2, and 3/4 the length of Cell 2 (stations 2a, 2b, and 2c respectively) allowed in-cell characteristics of wetland processing to be assessed. Many of the measured parameters showed sharp declines from inflow levels in the first one quarter of the cell before reaching 2a. Temperature declined after inflow and then remained fairly constant through the cell. Conductivity and pH values exhibited a distinct drop after inflow until reaching 2a and continued a gradual decline until outflow. Dissolved oxygen values declined sharply, then increased. Total solids showed a slight decrease at station 2a, lower values at 2b and 2c, and continued to decline until outflow. Both total (TP) and filterable ortho-phosphorus (FOP) showed gradual declines through the cell. Ammonia decreased nearly linearly to mid-cell (station 2b), then reduction slowed until outflow. Nitrate concentrations increased from inflow to station 2a, then gradually decreased until outflow. Fecal coliform bacteria exhibited an immediate decline from inflow to station 2a, and reached outflow levels by station 2b. Biochemical oxygen demand and chlorophyll exhibited similar patterns, declining distinctly by station 2a, decreasing further by station 2b, with a slight increase in values at 2c before reaching lowest concentrations at outflow.

Several rainfall events showed the need for a larger capacity system to accommodate peak flows. To increase the hydraulic loading capability of the constructed wetland system, and to assess the additional treatment associated with an increased length of the wetland cells, a fourth cell was constructed in series with Cell 1 during July, 1991. By adding this secondary cell, the same dimension as its precursor, reductions approximately twice as great as those produced by the primary wetland cells alone were recorded for temperature, conductivity, dissolved solids, and filterable ortho- and total phosphorus. Total solids were reduced nearly an additional 45% by the additional treatment, while sediment redox values declined an added 20%. Both total chlorophyll and biochemical oxygen demand were reduced about 15% more, while suspended solids, ammonia, and coliform bacteria were reduced only slightly more by this added cell treatment. There were increases in dissolved oxygen concentrations (131% increase from Cell 1 inflow until outflow from Cell 4, versus 43% average decrease in the primary treatment cells) and pH values (1% increase from inflow versus 11% decrease in primary treatment cells). The system will continue to be monitored during 1993 to document information on trapping and processing efficiencies in "maturing" constructed wetland cells. Future evaluators of similar wastewater treatment systems may wish to consider exploring capability of treatment cell designs, but, in view of the relatively small size of the treatment cells involved (20 x 80 feet), the measured reduction in pollutants indicates a successful point source management plan.

EVALUATION OF ARS AND SCS CONSTRUCTED WETLAND/ANIMAL WASTE TREATMENT PROJECT AT HERNANDO, MISSISSIPPI

INTRODUCTION

During the past two decades the beneficial role of aquatic plants for improving water quality has been thoroughly documented (Boyd, 1970; Sheffield, 1967; Yount, 1964). The production-trapping system of wetlands had been shown to remove nutrients, organic chemicals, heavy metals, and sediments from inflowing waters. Environmental engineers have recommended the re-establishment of wetlands where water quality has deteriorated since wetland removal (Kloetzli, 1981; Jones and Lee, 1980). Seidel (1976), Wolverton and McDonald (1975, 1976, and 1981) and Rogers et al. (1991) documented the efficiency of aquatic plants in removing organic chemicals from water. Simpson et al. (1983), Peverly (1985) and Lan et al. (1992) demonstrated the effective role that wetlands play in trapping heavy metals. Wieder and Lang (1984) described how wetlands help regulate stream chemistry and minimize acid mine drainage impact.

One result of natural wetlands research has been the knowledge that physical, chemical, and biological processes which occur in wetlands are similar to those occurring in mechanical sewage treatment plants. These processes also result in efficient uptake of chemicals and metals. Thus, many recent nutrient uptake and cycling studies conducted on wetlands have been concerned with their potential use as natural sewage treatment systems (Simpson et al., 1983; Boyt et al., 1976; Dolan et al., 1981) or as water purifiers (Sloey et al., 1978; Nichols, 1983).

Recent research interests have begun to focus on practical, applied uses of natural and constructed wetlands in the area of waste processing (Reed, 1991). Small municipalities are finding constructed wetlands an alternative to more costly conventional waste treatment plants (Gearheart, et al., 1989). Processing and disposing of concentrated on-farm animal waste, a major source of water quality deterioration, is a primary concern of the Soil Conservation Service and regulatory agencies. Thus, several projects for evaluating the ability of constructed wetlands to process animal waste have been initiated across the United States (Holmes et al., 1992; Ulmer et al., 1992; Krider and Boyd, 1992; Payne et al., 1992). The Mississippi Soil Conservation Service (SCS) and the Agricultural Research Service (ARS), National Sedimentation Laboratory in Oxford, Mississippi are cooperating on an on-farm dairy waste treatment project in DeSoto County, Mississippi. By agreement, SCS designed and constructed a lagoon and wetland cells and ARS is evaluating wetland cell processing efficiency.

This report provides:

1) An overview of project history.
2) Summaries of measured environmental and water quality parameters.
3) Results and limited discussion for the eighteen month period from May, 1991 until November, 1992.

PROJECT OVERVIEW

Primary Wetland Treatment (Lagoon and Cells 1, 2, 3)

-1990-

A constructed wetland (Fig. 1) for treatment of dairy farm wastewater was implemented in DeSoto County, MS during 1990. Construction of the anaerobic lagoon and three parallel wetland cells at the site on the Allan Scott Farm near Hernando was completed during May, 1990. All cells were immediately planted in bulrush (*Scirpus validus*) at one foot intervals using rhizome cuttings purchased from a wildlife supply company. Standing water in the lagoon basin was used to flood the cells to allow plant growth. Subsequent rains, supplemented first with water pumped from the lagoon basin and then with well water, provided adequate water to maintain standing water in the cells for the remainder of the year. The anaerobic lagoon received inputs from milking equipment and tank cleanings, milking barn washings, loafing area runoff, and rainfall (see SCS design data, Table 1). Despite continued inputs from these sources, water level in the lagoon increased very slowly, probably due to high evaporation rates, and lateral seep through new levees until the basin sealed. An insufficient amount of water accumulated in the lagoon to allow a gravity fed water supply to the wetland cells during 1990.

Plant growth in the constructed wetland cells was rapid, with bulrushes reaching an average height of approximately eighteen inches by June, 1990. Also in June, flowering heads appeared on most plants, indicating good plant vigor and suitable substrate composition. Obvious rhizome elongation was observed during July as new shoots appeared adjacent to initial plantings. By August, original bulrush plantings had enlarged into dense mats within the cells, and by September the cells were covered by a uniformly dense monoculture with the majority of culms supporting flowering/seeding heads. Natural senescence of the plant population occurred in November and December, with all plants dead by 19 December, following abnormally low freezing temperatures.

-1991-

Re-emergence of bulrushes from rhizomes occurred in February, 1991, through the litter created by the previous year's growth. Rapidly expanding populations of duckweed (*Spirodela polyrhiza*) in the wetland cells were also observed during the spring of 1991, which spread to cover nearly all available water surface by May, 1991. Heavy rainfall during the spring months of 1991 rapidly elevated the water level in the anaerobic lagoon. On April 14, 1991, the gravity feed design for wastewater transport from the lagoon to the wetland cells began functioning. Withdrawal from the lagoon to wetland cells was made from approximately one foot below water surface by use of a threaded "L" attachment to the outflow pipe. Withdrawal level in the water column was maintained by periodic adjustment as lagoon stage fluctuated. Inflow rates for each cell were set using the in-line gate valves installed during construction, with discharge measured volumetrically at the point of introduction to the cell. Based upon concomitant rainfall amounts and anaerobic lagoon water level, discharges to each cell were calibrated to yield 3.0 liters per minute.

Following initial inflow from the anaerobic lagoon to the cells, bulrushes exhibited distinct browning of the culm tips, ranging from 0 to 4 inches from the tip down the culm on 26 April

1991. On 29 April, continuing heavy rain threatened to cause back flow to the milking barn, and Mr. Scott opened all valves to discharge water from the lagoon through the cells to prevent contamination of the milking facility. This emergency flushing had no visible affect on plant growth. At this time, bulrushes in Cell 1 appeared in good condition with most plants flowering and only a very small percentage exhibiting brown culm tips. In Cell 2, very few plants were flowering, and most culms were browned up to 1/3 their length from the tip. Conditions were intermediate in Cell 3, with approximately 1/3 of the plants flowering, and only about 1/2 showing browning of the culm tops. Plant density in Cell 2 was also only about 1/2 of that in Cells 1 and 3.

By 13 May, 1991 plants in all cells appeared to have stabilized, but death of browned culms created sparser stands in some portions of Cells 1 and 2. By late May, acute effects from wastewater loading in cells were less marked, and no further browning of the culms was observed. Most unaffected plant culms in all cells were flowering, and plant densities were high in all cells with the exception of some notable sparsity in the lower 1/4 of Cell 2. No further evidence of plant stress was noted; and during June large numbers of new emergent shoots developed flowering heads, and plant densities in all cells remained very high for the remainder of the year.

The variability of hydrologic and environmental conditions reduced ability to maintain constant inflow to wetland cells. Control of inflow rates to the 3 cells from the lagoon reflected problems associated with fluctuating lagoon water levels, settling and clogging of solids in supply pipes, and high evaporation rates in the cells. Greater ability to control inflow was attained by the addition of 2" ball valves in line on wetland cell inflow standpipes during May, 1991. Rapid water level decline (Figure 4) in the anaerobic lagoon during June, July, and early August, 1991 prompted a reduction of cell inflow rates to 0.5 liters per minute, but, at such a low rate, settling and clogging of pipes and valves accelerated. During August, after consulting with Ross Ulmer (SCS), inflow ball valves were removed, and standpipes were fitted with threaded end caps with orifices. End caps with different sized orifices could be used to achieve desired flow rates. Original in-ground valves were opened fully to prevent occlusion. Using this method, a cell inflow rate of 1.0 liter per minute was implemented, and the frequency of remedial action was greatly decreased. Also during the summer of 1991, a fourth cell, Cell 4, was constructed in series with Cell 1 to allow greater loading capacity and assessment of further treatment.

In October, 1991, water level in the anaerobic lagoon fell to near the minimum level for feeding the wetland cells by gravity flow. A constant head tank was placed on the lagoon levee and plumbed to feed the outflow pipe. An electric impeller pump controlled by a timer maintained water in the tank, allowing the cells to receive consistent pressure and, consequently, consistent inflow.

Also in October, 1991, senescence of 30-40% of bulrushes occurred in the wetland cells coincident with low temperatures. Natural replacement shoots were evident and growing at this time, though in limited numbers compared to the observed senescence. Nearly all bulrush culms were dead on 4 November, and all had died due to freezing temperatures by 25 November, 1991.

On 2 December, 1991, the constant head tank system was bypassed to allow Mr. Scott to discharge water from the lagoon before backflow into his milking barn and resulting

contamination of equipment occurred. This modification remained in effect in case of future need until 27 January, 1992, when the constant head tank was re-installed.

-1992-

During late February, *Daphnia* sp., which had been incidently noticed at earlier dates, exhibited extremely dense populations near inflow ends of the wetland cells. Daphnia were concentrated wherever the water's surface was open, and continued to be found in high concentrations through March. Duckweed continued to cover most available water's surface throughout the winter months, spreading as more of the dead bulrush material became lodged and submerged. Dead rush shoots formed a dense mat of submerged organic material filling the water column.

Emergence of bulrushes did not occur until late March, 1992, over four weeks later than during the previous year. This difference may have been due to the amount of dead plant material in the water column, water surface cover by duckweed, climatological conditions, or a combination of these and/or other chemical and physical occurrences. Initial growth was limited to edges of wetland cells, especially in Cell 1, inside of which nearly all of the previous years bulrush material had submerged, blocking the water column. Areas in cells where old plant material had not yet submerged showed faster re-emergence and denser cultures. While the two other cells developed nearly uniform monocultures, Cell 1 failed to attain mid-cell growth through June. At that time, dead plant material in Cell 1 was raked from the cell, and the water level subsequently lowered in July to approximately 4 inches in an effort to stimulate plant growth and maintain similar characteristics in the three treatment cells. This necessitated lowering the water level in Cell 4 also, and invalidated comparisons of Cells 1 and 4 with the other two cells during this period. Thus, data for Cells 1 and 4 were not used as replicates for analysis during the fall, 1992 season.

Plant populations in all cells became dense monocultures, flowered, and went to seed between June and September, 1992. During August, lodging was apparent in portions of each cell, especially Cell 3, which lies unprotected on the west side of the system and borders a large pasture. Observations during August, September, and October documented broadening areas of dying bulrushes in Cell 3. At the same time, large numbers of grasshoppers were observed on the rushes, apparently feeding on the epidermal tissue and causing many culms to bend and break. Additionally, a fungus similar to wheat rust was noticed to spread through most of the bulrush cultures, damaging other culms. These factors are probably responsible for the relatively early senescence of the bulrush populations in treatment cells 2 and 3. Cell 1, which had a lower water level and less submerged organic material, remained mostly green and vigorous through the end of October.

Secondary Wetland Treatment (Cell 4)

-1991-

Several rainfall events, especially in spring, 1991, showed the need for a larger capacity system to accommodate peak flows. To increase the hydraulic loading capability of the constructed wetland system, and to assess the additional treatment associated with an increased length of the wetland cells, a fourth wetland cell was constructed during July, 1991, in series with Cell 1 (Figure 1). The new cell, designated Cell 4, was planted in bulrush on 2 November, and a water

depth of approximately 8 inches was maintained. Subsequent freezing weather and frost occurred, and no noticeable growth of the plantings was evident during 1991.

-1992-

No viable bulrush plantings from the preceding fall were observed during the first four months of 1992. Thus, during late April and early May, 1992, Cell 4 was planted on staggered three foot centers with cuttings of viable shoot/rhizome cuttings taken from the primary treatment cells. Subsequent growth of the cuttings occurred during the following months. The plantings expanded as healthy clumps by early June and formed a nearly contiguous stand by early August. Flowering and seed production occurred in Cell 4, as in the primary wetland treatment cells, during July and August. Bulrushes in Cell 4 remained green and vigorous through the end of October.

METHODS

Eighteen parameters were routinely monitored at biweekly intervals from 6 May, 1991 to 19 October, 1992 (Table 2). The following sections briefly discuss each parameter. Overall maximum, minimum, and mean values for parameters are presented.

Water level elevations in the anaerobic lagoon were read from a staff gage located on the outflow control platform adjacent to the lagoon outlet pipe. Rainfall totals for the two week period prior to sampling were recorded using a Belfort Instrument Company Universal Raingage. Redox of sediments was measured using a Hach One pH Meter equipped with a combination electrode. Temperature, conductivity, dissolved oxygen and pH of wastewater were measured using a Martek Model XVII water quality meter and combination probe. Total and dissolved solids were determined by filter technique, and suspended solids was calculated as the difference (American Public Health Association 1989). Physical and chemical variables were measured at cell inflow and outflow. In addition, 3 walkways were constructed equal distances apart in Cell 2 so that measurements could be taken between inflow and outflow (Fig. 1).

Samples for chemical analysis of nutrients were taken concurrently with physical measurements. Inflow and outflow samples were taken directly from the PVC standpipes. Within-cell samples from Cell 2 (stations 2a, 2b, and 2c) were taken longitudinally along the center of the cell's length using a Black and Decker rotary hand pump. Lagoon samples were taken from the end of the outflow control platform at a depth of approximately one foot (the area of wastewater extraction to the wetland cells) also using the rotary hand pump. Filterable ortho-phosphorus and total phosphorus were analyzed according to APHA (1989) guidelines using the ascorbic acid spectrophotometric method. Nitrate and ammonia were measured using a Technicon TRAACS autoanalyzer, also according to APHA guidelines.

Biological oxygen demand, chlorophyll, and total coliforms were measured according to APHA guidelines (1989). Five day carbonaceous biological oxygen demand, CBOD 5, was measured using a YSI Model 50B oxygen meter with model 5730 probe. Addition of a nitrification inhibitor (TCMP, Hach Corporation) was used to allow only carbonaceous oxygen demand to be measured. Coliforms were enumerated using the membrane filter technique with media supplied by Sartorius Corporation (M FC media) and HACH Corporation (M FC media with rosalic acid

specificity enhancer). Filters used were Millipore Corporation 0.45 μm pore size grid filters. Coliform counts given are number of colony forming units (CFU's) per 100 ml sample.

RESULTS

Below are discussions of each parameter measured during the study, providing overall average treatment efficiencies and seasonal trends in each of the three original wetland cells. A summary of trapping and processing efficiencies by the wetland cells follow.

Rainfall (RAIN)

The reporting period began May, 1991; however, anomalous rainfall immediately prior to the reporting period may be relevant to some interpretations made based upon this data. Over 14 inches of rain were recorded at the wetland study site during April, 1991. Subsequent rainfall in 1991 was below average for the area, while 1992 precipitation was near average. Rainfall amounts for the study period are presented in Figure 3.

Lagoon Level (GAGE)

Lagoon water storage peaked during winter and spring wet seasons, then decreased through the summer and fall each year. Lagoon level was apparently predominantly controlled by rainfall amounts and evaporation potential (Figure 4).

Discharge (Q)

While maintenance of uniform inflow to the treatment cells was attempted, various factors caused some fluctuation, primarily before implementation of the orifice plugs and head tank (Table 3). Recorded inflow to the treatment cells was within 0.25 liters per minute of the desired 1 liter per minute value during more than 85% of the study period, with 9 records below this level and 4 records above. Discharge from the wetland cells was recorded at only one half of the measurements, indicating 50% attainment of zero discharge from the system. Of actual discharge recorded, 52% was less than 0.75 liters per minute, and 30% was less than 1.25 liters per minute. Only eight measurements exceeded 1.25 liters per minute (occurring following rainfall events). [This analysis excludes measurements taken immediately following flushing of the cells during December 1991 necessary to lower the lagoon and prevent milking barn contamination.]

Temperature (TEMP)

An overall reduction in temperature was seen as effluent moved through the constructed wetland cells. Water temperatures, on average, were 11.44% lower at outflow stations than upon entering the cells (Table 4). This reduction was likely due to physical processes such as shading by the wetland plants and the shallower mass of water within the wetland cells. The reduction was most evident during winter, accompanying cooler air temperatures, when waste water temperatures of outflowing water were nearly 25% lower than those of inflowing water (Figure 5). Values within the wetland cells during the study period showed expected seasonal fluctuations (Figure 6). Inflow extremes ranged from a maximum of 30.3 to a minimum of 7.2. Outflows ranged from 27.3 to a minimum of 1.5 degrees Celsius (Table 5).

Conductivity (COND)

Conductivity exhibited an overall reduction of 26.44% (Figure 2). Highest reduction of recorded conductivity occurred during the cooler months (Figure 7). Raw conductivity values showed an apparent seasonal fluctuation, but values were distinctly higher in 1992 than during 1991 (Figure 8). Maximum conductivity measured from inflow was 773 umhos/cm, and the minimum was 28 umhos/cm. Outflows ranged from 785 to 103 umhos/cm (Table 5).

Dissolved Oxygen (DO)

Dissolved oxygen values of the waste water decreased markedly with passage through the treatment cells (42.95% reduction, Table 4). Expected increases were seen only during the initial season of operation (summer 1991, Figure 9). Otherwise, reduced oxygen levels occurred since 1991, attributable mostly to biochemical demand, shading from the dense bulrush stand, and to duckweed which quickly colonized even small open areas of the water surface. Definite increases in DO were seen within the cells by creating a depth profile of oxygen values through Cell 2 (Mid-water column - Figure 10, and just below water surface - Figure 11). These increases, however, were routinely lost at the outflow pipe because of bottom withdrawal. Although greater reductions of dissolved oxygen occurred during 1992, overall DO values increased relative to 1991 concentrations (Figure 12). Recorded measurements for treatment cells ranged from 6.37 to 0.03 mg/L for inflows, while outflows ranged from 5.76 to 0.03 mg/L (Table 5).

pH (PH)

A small decrease in pH was observed for water flowing through the wetland cells (average 11.01% decrease, Table 4). This trend toward acidification resulted in outflow values below normal for natural surface waters in the area. Highest reductions in pH were observed during the winter months (Figure 13). Raw values showed an apparent minor seasonal response (Figure 14). Inflow pH ranges were from 8.50 to 6.13; outflow values ranged from 7.35 to 5.66 (Table 5).

Redox (RED)

Though values fluctuated widely throughout the study period (Figure 15), sediment redox was overall 123.19% lower at outflow stations than inflow stations (Table 4). This reduction may or may not be seasonally linked (Figure 16), with inflow values of 311 to (-)259, and outflows of 395 to (-)270 (Table 5).

Total Solids (TS)

For the reporting period, 31.70% of inflowing waste water total solids were removed by the wetland cells (Table 4). Total solids maintained higher levels during 1992 than 1991 (Figure 17), but reduction efficiencies were considerably higher during 1992 despite the elevated loading (Figure 18). This increase in trapping efficiency probably resulted due to the large amount of senescent plant material added to the water column during the 1991 winter months. Reduction was highest during summer 1992, when it reached nearly 45%. The sharp decline in TS removal efficiency in the fall of 1992 was associated with the suspended solid component (see below),

which fell by over one-third while dissolved solids removal efficiency increased. Relative contributions of dissolved and suspended components to total solids can be seen in Figure 17. Cell inflow concentrations for TS ranged from 749 to 202 mg/L while the outflow station measurements varied from 605 to 161 mg/L (Table 5).

Dissolved Solids (DS)

Mean dissolved solids removal by the cells averaged 22.08% (Table 4) over the study period. Reduction efficiency following initiation of wetland operation was less than 10% during the summer of 1991, but climbed to greater than 25% for most of the remainder of the study period (slightly less in summer 1992, Figure 19). Dissolved solids values rose during the summer and fall, 1991, fell slightly during winter, then rose to higher levels during the growing season of 1992 (Figure 20). Dissolved solids at inflow stations were measured between 510 and 107 mg/L, and outflow stations had a maximum of 467 and a minimum of 132 mg/L (Table 5).

Suspended Solids (SS)

Mean suspended solids removal efficiency was 59.71% (Table 4). Efficiency was low (ca. 22%) during the first season of operation. It climbed to greater than 60% in the fall, and remained relatively high until declining in the fall of 1992 (Figure 21). Interpretations of the sharp decrease in average efficiency during the fall of 1992 should be in context of an unprecedented negative efficiency for Cell 2, and the unavailability of an efficiency for Cell 1 that season (Table 8). Suspended solids concentrations peaked during warmer months (Figure 22), though disproportionate high values occurred intermittently. Inflow values ranged from 466 to 0.0 mg/L. Outflows varied from 255 to 0.0 mg/L (Table 5).

Filterable Ortho-Phosphorus (FOP)

Filterable ortho-phosphorus concentrations were reduced an average of 57.14% (Table 4). Reduction efficiencies rose from near 70% to over 85% during the first six months of operation, but declined steadily afterward from the onset of winter to the end of the analysis period (Figure 23). Binding by soils used to construct the wetland may account for the initial high reductions, which declined as these binding sites became saturated. Also, FOP concentrations entering the treatment cells rose gradually from inception of the project, with a peak during the winter and spring during plant senescence and decay (Figure 24), and these sources may be overloading the system. Maximum inflow concentration was 15.61 mg/L and minimum inflow measured was 0.93 mg/L. Outflow values ranged from a maixmum of 11.81 to a minimum of 0.14 mg/L (Table 5).

Total Phosphorus (TP)

Overall, total phosphorus removal averaged 69.76% (Table 4). Reduction efficiencies during the first three months of wetland operation averaged only slightly over 50%, but increased to over 80% in the following winter and spring season before declining to below 50% in the summer and fall of 1992 (Figure 25). Total phosphorus values remained fairly constant during the warmer months, but peaked during the colder months of November, 1991 through March, 1992. Growing season values in 1992, following the peak, were considerably higher than average values during

the preceding year (Figure 26). Extremes of inflow station concentrations were 69.04 and 2.83 mg/L. Outflow concentrations ranged from 12.75 to 0.25 mg/L (Table 5).

Ammonia (NH3)

Ammonia reduction by the wetland system proved to be consistently high, with an overall average for the three treatment cells of 91.06% (Table 4). Seasonal removal averaged about 90% for 1991 (Figure 27). Removal was elevated to over 95% in the spring of 1992, followed by a drop to near 80% in the summer, but with a subsequent increase to near 85% in the fall. Actual concentrations showed highly elevated peaks on some occasions during summer and fall, 1991, which were not observed during 1992 (Figure 28). Inflow concentrations ranged from 30.80 to 0.14 mg/L ammonia, while the outflows varied from 5.01 to < 0.01 mg/L (Table 5).

Nitrate (NO3)

Nitrate concentrations in the constructed wetland cells decreased an average of 23.01% in cells 1 and 2, but showed an increase of 330% in cell 3 (Table 4). Conceptually nitrate reductions are limited by continuing conversion of ammonia to nitrate in the cells. The nitrate created in the cells was apparently being converted to another form (probably gaseous) before outflow in cells 1 and 2, but was not in cell 3. This resulted in the negative average removal efficiency for cell 3, which appears large due to the small inflow concentrations. Inflow concentrations exhibited occasional spiked values, but generally were lowest during summer (Figure 29). An expected seasonal release of nitrate from senescent and decaying wetland plants occurred most noticeably in cell 3 during the fall and winter, 1991, and spring, 1992, seasons (Tables 7 and 8), resulting in large negative removal efficiencies during winter and spring months (Figure 30). Nitrate concentrations rose within cell 2 during those periods, but decreased to below inflow levels before discharge from the cell (Figure 31). A similar situation may have existed for cell 1, but in-cell nitrate values were not measured for that cell. Maximum inflow value for nitrate was from cell 3, measured at 0.32 mg/L. Undetectable levels of nitrate occurred at least once at all inflow sites. The maximum outflow concentration of nitrate, also from Cell 3, was 3.31 mg/L, and the minimum value at each outflow station <0.01 mg/L (Table 5).

Chlorophyll (CHL)

Chlorophyll values for the wetland system declined an average of 76.80% from inflow to outflow stations (Table 4). High levels of algal growth in the primary settling lagoon yielded high concentrations of chlorophyll entering the cells. Shading by bulrushes, duckweed, and organic debris decreased the ability of algae to grow inside the wetland treatment cells, resulting in much lower concentrations exiting the system. Settling of algae in the cells caused further decreases in chlorophyll concentrations. Concentrations of chlorophyll were reduced less than 30% in the cells during the first season of operation, but the subsequent 12 months had reductions of near 90% (Figure 32). The fall of 1992 had less than 60% reduction in chlorophyll values within the cells, coincident with the relatively early senescence of bulrushes that year (see general discussion above). Actual chlorophyll values entering the treatment cells remained fairly constant through 1991 (near 270 mg/L), then increased through 1992 to a peak value of 414 mg/L in the summer, before declining in the fall to only 78 mg/L (Tables 7 and 8). Outflow values were high during the first season of treatment at near 180 mg/L, then fell to 26 mg/L for fall and winter, 1991. Outflow values were somewhat higher for the spring and summer of 1992, before declining to

near the 1991 value in the fall. It is interesting to note that peak reduction in chlorophyll values coincided with peak input. General characteristics of chlorophyll values through the study period are presented in Figure 33. The maximum recorded chlorophyll concentration for an inflow station was 1505 mg/L, and the minimum inflow value was 13.4 mg/L. Outflow concentrations ranged from 759 to 1.14 mg/L (Table 5).

Biochemical Oxygen Demand (BOD)

Carbonaceous biochemical oxygen demand 5-day tests indicated that there was an overall reduction in CBOD5 of 70% during this study period (Table 4). After a 42.30% reduction for the initial three months of operation, CBOD5 was reduced nearly 80% for the remainder of the analysis period (Figure 34). Actual values began relatively high for both inflow and outflow stations (Table 7), but decreased to lower concentrations for successive seasons (the graphical presentation of actual values in Figure 35 is difficult to interpret). The maximum CBOD5 value measured for an inflow was 80 mg/L; the minimum 9.67 mg/L Outflow demand concentrations ranged between 48 and 0.33 mg/L (Table 5). (Data contained in this report supercedes any previously reported values.)

Coliform Bacteria (COL)

The wetland treatment cells were very efficient at removing coliform bacteria from wastewater, with an overall average reduction of 95.78% (Table 4). Reduction efficiencies for the first season of operation were greater than 70%, peaking during winter and spring 1991-1992 at greater than 99% removal. Efficiency remained over 90% during summer of 1992, but dropped sharply in the fall 1992 season to an average of only 37.10%. Recorded levels of coliforms during these seasons showed sporadic elevated levels, mainly from July, 1991 through June 1992, with a definite peak during December and January 1991/1992. The maximum seasonal inflow occurred during winter, while maximum outflows occurred during the fall season of both 1991 and 1992 (Tables 7 and 8). Inflow values recorded were between 101,000 and 0 colony forming units (CFU's). Outflow densities ranged from 8500 to 0 CFU's (Table 5).

Chemical Oxygen Demand (COD)

Chemical oxygen demand was measured quarterly for the wetland treatment system, and showed a 64.97% average reduction over the analysis period (Table 4). Efficiencies calculated have ranged from a maximum of 83.55% in December, 1991, to a minimum of 35.86% in August, 1991. The maximum inflow COD value was 445 mg/L, and the minimum 144 mg/L. Outflow COD measured was between 167.5 and 50 mg/L (Table 6).

CELLS 1, 2, 3 (INFLOW - OUTFLOW REDUCTIONS)

A direct comparison of mean reduction percentages for parameters monitored during this study can be made using Figure 2. Greatest reductions were seen for coliform bacteria (96%), ammonia (91%), chlorophyll concentrations (77%), and, to a lesser degree, for biochemical and chemical oxygen demand (65-70%), suspended solids (60%), and total and filterable ortho-phosphorus (70 and 57% respectively). In view of the relatively small size of the treatment cells involved (20 X 80 feet), the measured reduction in pollutants indicates a successful point source management plan.

CELL 2 (WITHIN CELL CHARACTERISTICS)

Use of catwalks at 1/4, 1/2, and 3/4 the length of Cell 2 (stations 2a, 2b, and 2c respectively) allowed in-cell characteristics of wetland processing to be assessed. Many of the measured parameters showed sharp declines from inflow levels before reaching 2a. Temperature dropped distinctly after inflow then remained fairly constant through the cell. Conductivity and pH values exhibited a distinct drop after inflow until reaching 2a, then continued a gradual decline until outflow. Dissolved oxygen values dropped sharply, then increased through the cell. Total solids showed slight decrease at station 2a, lower values at 2b and 2c, and dropped considerably more before outflow. Mean suspended solids values were higher at station 2a than at inflow, causing the only slight decrease observed for total solids at that station. Both total and filterable orthophosphorus showed gradual declines through the cell, though FOP reduction was not as great. Ammonia decreased nearly linearly to mid-cell (station 2b) then reduction slowed through outflow. Nitrate concentrations increased from inflow to station 2a, then gradually decreased until outflow. Fecal coliform bacteria exhibited an immediate decline from inflow to station 2a, and reached outflow levels by station 2b. Biochemical oxygen demand and total chlorophyll exhibited similar patterns in the cell, declining sharply by station 2a, decreasing further by station 2b, with a slight increase in values at 2c before reaching lowest levels at outflow.

CELL 4 (SECONDARY WETLAND TREATMENT)

After construction and establishment of bulrushes in Cell 4, further treatment of wastewater was possible beyond the lagoon and primary wetland cell #1 during winter, 1991 and spring and summer, 1992. By adding this secondary cell, the same dimension as its precursor, reductions approximately twice as great as those produced by the primary wetland cells alone were recorded for temperature, conductivity, dissolved solids, and filterable ortho- and total phosphorus. Total solids were reduced nearly 45% more by the additional treatment, while sediment redox values dropped an added 20%. Both total chlorophyll and biochemical oxygen demand were reduced by an additional 15%, while suspended solids, ammonia, and coliform bacteria were reduced only slightly more by this added cell. There were increases in dissolved oxygen concentration (131% increase from 1i to 4o versus 43% average decrease in the primary treatment cells) and pH values (1% increase from inflow versus 11% decrease in primary treatment cells). Future evaluators of similar wastewater treatment systems may wish to consider exploring capability of designs with longer and narrower treatment cells.

1993 PROGRAM OF WORK

Routine weekly maintenance and bi-weekly sampling during 1993 should produce worthwhile information on trapping and processing efficiencies in "maturing" cells.

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Table 1. *SCS Calculated Data for Loading Estimates.*

RAINFALL RUNOFF AREA	
ROOF AND CONCRETE	3784 sq. ft.
ANAEROBIC LAGOON	22950 sq. ft.
WETLAND CELLS	6000 sq. ft.
DAIRY WASTE PRODUCTION (Based upon 100 cow dairy herd)	365 cu. ft./day

Table 2. *Parameters Monitored in Constructed Wetland Study.*

Abbreviations in parentheses

STAFF GAGE	(GAGE)
RAIN GAGE	(RAIN)
CBOD 5	(BOD)
COLIFORMS	(COL)
TEMPERATURE	(TEMP)
CONDUCTIVITY	(COND)
DISSOLVED OXYGEN	(DO)
pH	(PH)
REDOX	(RED)
CELL INFLOW/OUTFLOW	(Q)
TOTAL SOLIDS	(TS)
SUSPENDED SOLIDS	(SS)
DISSOLVED SOLIDS	(DS)
CHLOROPHYLL	(CHL)
FILTERABLE ORTHO PHOSPHORUS	(FOP)
TOTAL PHOSPHORUS	(TOP)
NITRATE	(NO3)
AMMONIA	(NH3)
CHEMICAL OXYGEN DEMAND	(COD) quarterly

Table 3. *Inflow and Outflow Rates for Wetland Cells.*

Range (Liters/minute)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
		CELL 1,2,3 INFLOWS		
0.001 - 0.750	9	10.00	9	10.00
0.751 - 1.250	77	85.60	86	95.60
1.251 - 1.750	2	2.20	88	97.80
1.751 - 2.250	2	2.20	90	100.00
		CELL 1,2,3 OUTFLOWS		
Zero	44	50.00	44	50.00
0.001 - 0.750	23	26.10	67	76.10
0.751 - 1.250	13	14.80	80	90.90
1.251 - 1.750	5	5.70	85	96.60
1.751 - 2.250	1	1.10	86	97.70
>2.250	2	2.30	88	100.00
		CELL 4 OUTFLOWS		
Zero	9	75.00	9	75.00
1.751 - 2.250	1	8.30	10	83.30
>2.250	2	16.70	12	100.00

Table 4. *Mean Values for Sampling Sites and Reduction Percentages by Cell for the Study Period.*[*]

SITE	N	TEMP (deg. C)	COND umhos/cm	DO (mg/L)	PH	RED mV	TS (mg/L)	DS (mg/L)	SS (mg/L)
Lg	41	21.01	345	2.83	6.94	-40	535	373	162
1i	41	19.28	307	2.26	7.01	-26	470	338	137
1o	41	17.36	213	1.12	6.18	33	301	257	44
2i	41	19.72	338	2.94	6.93	-84	462	358	109
2a	41	17.02	282	1.16	6.36	NA	456	334	125
2b	41	16.70	277	1.51	6.25	NA	389	308	84
2c	41	16.71	251	1.72	6.21	NA	374	309	82
2o	41	17.13	239	1.85	6.16	-14	313	260	56
3i	41	19.60	340	2.72	6.88	-135	486	362	125
3o	41	17.41	274	1.59	6.19	-56	355	308	47
4o	21	14.76	166	5.22	7.09	15	254	199	55
CELL 1		9.96%	30.54%	50.33%	11.85%	228.14%	35.98%	24.12%	68.08%
CELL 2		13.15%	29.35%	37.11%	11.17%	82.82%	32.15%	27.25%	48.99%
CELL 3		11.20%	19.42%	41.42%	10.01%	58.60%	26.97%	14.88%	62.06%
CELL 4		14.98%	21.93%	-366.07%	-14.72%	53.45%	15.56%	35.44%	-25.78%
1i-4o		23.44%	45.77%	-130.97%	-1.14%	159.64%	45.94%	41.27%	59.85%
AVG-1,2,3		11.44%	26.44%	42.95%	11.01%	123.19%	31.70%	22.08%	59.71%

SITE	N	FOP (mg/L)	TP (mg/L)	NH3 (mg/L)	NO3 (mg/L)	CHL (mg/L)	BOD (mg/L)	COL CFU/100 ml	COD (mg/L)
Lg	41	7.07	13.62	7.11	0.06	491	40	24465	512
1i	41	6.70	13.47	6.50	0.05	268	37	12686	247
1o	41	1.87	3.27	0.38	0.04	79	13	907	104
2i	41	6.88	14.44	6.14	0.07	284	36	16007	306
2a	41	5.51	9.19	4.02	0.35	118	20	1327	321
2b	41	4.55	6.27	1.45	0.20	91	14	308	196
2c	41	3.40	4.97	0.54	0.17	103	14	230	241
2o	41	2.79	3.78	0.32	0.05	62	9	390	94
3i	41	7.01	14.22	7.47	0.06	291	37	15472	299
3o	41	4.21	5.72	1.18	0.26	53	11	473	96
4o	21	0.28	1.27	0.37	0.03	31	10	295	197
CELL 1		72.04%	75.70%	94.22%	22.32%	70.56%	65.72%	92.85%	57.81%
CELL 2		59.46%	73.82%	94.80%	23.70%	78.12%	73.66%	97.56%	69.22%
CELL 3		39.92%	59.75%	84.17%	-329.57%	81.72%	70.67%	96.94%	67.87%
CELL 4		85.03%	61.16%	2.63%	25.00%	61.28%	21.50%	67.45%	-105.21%
1i-4o		95.82%	90.57%	94.31%	40.00%	88.60%	73.09%	97.67%	20.18%
AVG-1,2,3		57.14%	69.76%	91.06%	-94.51%	76.80%	70.01%	95.78%	64.97%

[*] i is inflow, o is outflow, a, b, c, are 1/4, 1/2, 3/4 cell length from inflow; Lg is lagoon.

Table 5. *Maximum and Minimum Values for Sampling Sites During the Study Period.*

MAXIMUM VALUES

SITE	N	GAGE (feet)	RAIN (inches)	TEMP (deg. C)	COND umhos/cm	DO (mg/L)	PH	RED (mV)	TS (mg/L)	DS (mg/L)	SS (mg/L)	FOP (mg/L)	TP (mg/L)	NH3 (mg/L)	NO3 (mg/L)	CHL (mg/L)	BOD (mg/L)	COL (CFU/100 ml)
LG	41	8.16	6.75	29.0	607	14.46	8.37	272	875	476	475	11.83	45.40	27.73	0.22	2065	80	105000
1i	41	8.16	6.75	27.1	605	5.82	8.46	263	717	491	345	15.61	58.33	23.03	0.10	860	72	76000
1o	41	8.16	6.75	25.6	459	4.87	7.00	362	491	432	176	5.96	8.99	1.38	0.19	700	48	8500
2i	41	8.16	6.75	30.3	773	6.37	8.19	264	610	510	245	14.84	69.04	15.54	0.24	861	62	101000
2a	41	8.16	6.75	26.0	605	2.72	7.19	NA	1290	630	660	11.20	79.47	10.74	1.97	441	61	11000
2b	41	8.16	6.75	25.9	781	5.52	6.95	NA	721	420	341	11.21	17.86	8.01	1.71	579	50	2900
2c	41	8.16	6.75	25.2	687	5.40	6.95	NA	882	710	537	8.82	12.47	5.38	1.93	906	47	1267
2o	41	8.16	6.75	25.2	655	5.76	7.04	395	605	467	255	7.48	9.52	1.92	0.35	759	45	4800
3i	41	8.16	6.75	28.5	612	6.04	8.50	311	749	488	466	12.50	63.45	30.80	0.32	1505	80	80000
3o	41	8.16	6.75	27.3	785	4.32	7.35	276	549	463	233	11.81	12.75	5.01	3.31	508	44	2340
4o	21	8.04	6.75	23.7	324	12.54	7.83	275	426	357	273	0.73	3.64	1.21	0.11	103	17	1000

MINIMUM VALUES

SITE	N	GAGE (feet)	RAIN (inches)	TEMP (deg. C)	COND umhos/cm	DO (mg/L)	PH	RED (mV)	TS (mg/L)	DS (mg/L)	SS (mg/L)	FOP (mg/L)	TP (mg/L)	NH3 (mg/L)	NO3 (mg/L)	CHL (mg/L)	BOD (mg/L)	COL (CFU/100 ml)
LG	41	5.5	0	6.5	197	0.03	5.75	-204	364	252	9	2.09	5.62	0.55	<0.01	27.56	17.67	200
1i	41	5.5	0	7.6	28	0.06	5.71	-202	202	107	3	0.93	2.83	0.14	<0.01	13.40	18.00	0
1o	41	5.5	0	5.3	105	0.03	5.69	-270	163	152	<1	0.14	0.25	<0.01	<0.01	2.14	0.33	0
2i	41	5.5	0	7.2	28	0.03	6.13	-226	270	224	<1	0.94	3.36	0.55	<0.01	17.20	15.67	0
2a	41	5.5	0	3.1	5	0.10	5.84	NA	206	171	6	0.95	2.12	0.13	<0.01	4.63	2.13	0
2b	41	5.5	0	4.7	113	0.14	5.71	NA	233	189	12	0.56	1.49	<0.01	<0.01	2.87	1.00	0
2c	41	5.5	0	4.3	106	0.03	5.62	NA	169	155	<1	0.24	0.87	<0.01	<0.01	2.54	1.33	0
2o	41	5.5	0	2.1	103	0.03	5.77	-191	161	132	4	0.21	0.36	<0.01	<0.01	2.87	0.33	0
3i	41	5.5	0	7.4	198	0.04	5.95	-259	241	240	<1	1.32	4.38	0.55	<0.01	14.80	9.67	0
3o	41	5.5	0	1.5	106	0.03	5.66	-212	165	154	<1	0.52	0.91	<0.01	<0.01	1.14	1.00	0
4o	21	6.4	0	7.0	77	0.25	6.36	-197	151	87	15	0.05	0.42	<0.01	<0.01	0.85	2.67	0

Table 6. *Chemical Oxygen Demand (COD) for Sampling Sites and Reduction Percentages by Cell.*

SITE	22-May-91	2-Jun-92	5-Aug-91	6-Oct-92	4-Nov-91	AVERAGE
1i	144.00	445.00	145.00	210.00	290.00	246.80
1o	98.00	167.50	93.00	NA	58.00	104.13
2i	240.00	355.00	NA	220.00	410.00	306.25
2a	114.50	602.50	642.00	124.00	122.00	321.00
2b	135.50	290.00	NA	262.50	97.00	196.25
2c	122.50	210.00	662.50	119.00	89.00	240.60
2o	132.50	105.00	NA	87.50	52.00	94.25
3i	225.00	445.00	NA	225.00	300.00	298.75
3o	101.50	114.00	NA	118.50	50.00	96.00
4o	NA	197.00	NA	NA	NA	197.00
LG	NA	937.00	607.50	245.00	260.00	512.38
CELL 1	31.94%	62.36%	35.86%	NA	80.00%	57.81%
CELL 2	44.79%	70.42%	NA	60.23%	87.32%	69.22%
CELL 3	54.89%	74.38%	NA	47.33%	83.33%	67.87%
CELL 4	NA	-17.61%	NA	NA	NA	-89.20%
1i-4o	NA	55.73%	NA	NA	NA	20.18%
AVG-1,2,3	43.88%	69.05%	35.86%	53.78%	83.55%	64.97%

Table 7. *Mean Values for Sampling Sites by Season for 1991.*

SUMMER 1991																		
ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	9	7.68	0.81	26.09	259	2.43	6.66	-76	461	316	146	3.39	6.5	8.53	0.04	923	36	13767
1i	9	7.68	0.81	23.64	235	0.42	6.45	19	326	237	89	2.12	4.87	5.15	0.04	234	48	767
1o	9	7.68	0.81	23.31	188	0.68	5.91	-62	288	224	64	0.31	2.07	0.15	0.03	234	25	417
2a	9	7.68	0.81	22.85	229	0.25	6.01	NA	328	257	71	1.64	4.05	2.32	0.05	199	28	280
2b	9	7.68	0.81	22.81	214	0.25	5.9	NA	306	241	65	0.99	3.03	0.34	0.03	108	27	93
2c	9	7.68	0.81	22.78	205	0.24	5.92	NA	287	246	41	0.68	2.67	0.27	0.03	120	24	173
2i	9	7.68	0.81	23.54	234	1.14	6.49	-66	362	262	100	2.2	4.74	2.68	0.05	243	40	856
2o	9	7.68	0.81	22.73	197	0.31	5.87	-69	302	223	79	0.45	2.17	0.47	0.03	201	26	159
3i	9	7.68	0.81	23.6	247	0.31	6.5	-116	382	279	103	2.77	6.45	9.69	0.03	361	47	3790
3o	9	7.68	0.81	22.36	210	0.41	5.9	-83	343	256	86	1.61	3.4	0.35	0.02	103	26	225
REDUCTION %		CELL 1	SUM91	1.40%	19.91%	-61.90%	8.37%	433.67%	11.81%	5.55%	28.51%	85.38%	57.49%	97.09%	25.00%	-0.07%	46.97%	45.61%
		CELL 2	SUM91	3.44%	15.76%	72.81%	9.55%	-4.54%	16.42%	14.78%	20.70%	79.55%	54.22%	82.46%	40.00%	17.09%	36.00%	81.45%
		CELL 3	SUM91	5.25%	15.03%	-32.26%	9.23%	28.82%	10.32%	8.09%	16.34%	41.88%	47.29%	96.39%	33.33%	71.50%	43.93%	94.06%
		AVG-1,2,3	SUM91	3.36%	16.90%	-7.12%	9.05%	152.65%	12.85%	9.47%	21.85%	68.93%	53.00%	91.98%	32.78%	29.50%	42.30%	73.70%
MEAN VALUES		Inflows	SUM91	23.59	238.67	0.62	6.48	-54.48	356.75	259.32	97.44	2.36	5.35	5.84	0.04	279.36	45.06	1804.22
		Outflows	SUM91	22.80	198.41	0.47	5.89	-71.38	310.96	234.52	76.45	0.79	2.55	0.32	0.03	179.53	25.84	267.03

FALL 1991																		
ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	6	6.01	0.93	23.77	365.67	0.71	6.75	-147	542	405	137	3.58	10.43	9.39	0.03	468	33	24800
1i	6	6.01	0.93	23.62	351.67	1.66	6.92	-69	531	382	149	3.26	5.93	5.56	0.04	141	27	11000
1o	6	6.01	0.93	20.58	260.17	0.8	6.27	-42	330	307	23	0.21	0.94	0.44	0.02	25	7	3600
2a	6	6.01	0.93	18.78	326.4	1.03	6.55	NA	706	445	261	3.42	6.03	4.23	0.48	163	24	4783
2b	6	6.01	0.93	16.6	304.5	1.29	6.37	NA	483	380	103	1.66	4.14	1.6	0.09	139	10	950
2c	6	6.01	0.93	18.54	299.6	2.18	6.54	NA	498	355	143	0.49	2.6	1.04	0.01	225	19	367
2i	6	6.01	0.93	23.86	364.4	3.09	6.83	-151	526	403	123	3.82	7.41	6.22	0.11	328	37	31000
2o	6	6.01	0.93	17.5	272.33	2.6	6.28	47	414	355	59	0.4	1.54	0.35	0.03	37	6	434
3i	6	6.01	0.93	23.24	364.6	1.64	6.77	-126	540	412	129	3.92	6.54	6.31	0.02	303	30	16600
3o	6	6.01	0.93	20.04	302.4	1.11	6.23	-60	427	367	60	1.1	4.01	0.75	0.03	18	8	1258
REDUCTION %		CELL 1	FALL 91	12.87%	26.02%	51.81%	9.39%	39.03%	37.86%	19.66%	84.45%	93.56%	84.15%	92.09%	50.00%	82.15%	72.49%	67.27%
		CELL 2	FALL 91	26.66%	25.27%	15.86%	8.05%	131.17%	21.25%	11.94%	51.88%	89.53%	79.22%	94.37%	72.73%	88.67%	83.27%	98.60%
		CELL 3	FALL 91	13.77%	17.06%	32.32%	7.98%	52.14%	20.96%	10.86%	53.24%	71.94%	38.69%	88.11%	-50.00%	93.95%	74.61%	92.42%
		AVG-1,2,3	FALL 91	17.77%	22.78%	33.33%	8.47%	74.11%	26.69%	14.15%	63.19%	85.01%	67.35%	91.52%	24.24%	88.26%	76.79%	86.10%
MEAN VALUES		Inflows	FALL 91	23.57	360.22	2.13	6.84	-115.39	532.25	398.80	133.45	3.67	8.63	6.03	0.06	257.61	31.18	19533.33
		Outflows	FALL 91	19.37	278.30	1.50	6.26	-18.52	390.31	342.85	47.46	0.57	2.16	0.51	0.03	26.93	7.04	1763.92

WINTER 1991																		
ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	7	7.47	2.35	9.73	231.83	3.13	7.31	-1	437	346	91	6.53	15.94	6.49	0.07	255	39	54667
1i	7	7.47	2.35	11.2	239.29	2.73	7.68	101	425	333	122	8.53	19.87	8.99	0.06	237	36	33000
1o	7	7.47	2.35	9.27	152	1.75	6.43	230	249	221	28	1.91	2.08	0.4	0.08	26	7	0
2a	7	7.47	2.35	7.55	169.17	1.79	6.6	NA	309	254	55	3.2	4.18	1.26	1.04	48	10	500
2b	7	7.47	2.35	7.72	157.33	2.81	6.49	NA	304	253	51	2.36	2.68	0.31	0.5	99	7	0
2c	7	7.47	2.35	7.6	154	3.61	6.48	NA	288	244	44	1.71	2.06	0.52	0.53	55	7	150
2i	7	7.47	2.35	10.64	227.29	3.62	7.3	34	450	336	114	6.2	19.04	8.06	0.08	307	42	45000
2o	7	7.47	2.35	8.11	159.86	3.05	6.35	125	289	233	56	1.19	1.43	0.33	0.09	13	6	67
3i	7	7.47	2.35	11.19	232.29	3.35	7.26	-127	420	323	97	7.05	19.73	6.91	0.08	239	40	42000
3o	7	7.47	2.35	8.2	182.71	2.28	6.59	-15	333	282	51	3.11	4.18	1.45	0.67	74	10	0
4o	2	7.81	1	9.15	83.5	10.91	7.68	119	260	113	147	0.14	0.53	NA	NA	40	11	0
REDUCTION %		CELL 1	WIN91	17.23%	36.48%	35.90%	16.28%	-128.97%	41.30%	33.57%	77.02%	77.61%	89.53%	95.55%	-33.33%	88.96%	79.25%	100.00%
		CELL 2	WIN91	23.78%	29.87%	15.75%	13.01%	-269.01%	35.81%	30.65%	51.07%	80.81%	92.49%	95.91%	-12.50%	95.69%	84.85%	99.85%
		CELL 3	WIN91	28.72%	21.34%	31.94%	9.23%	88.11%	20.69%	12.82%	47.04%	55.89%	78.81%	79.02%	-737.50%	69.15%	75.36%	100.00%
		CELL 4	WIN91	1.29%	45.07%	-523.43%	-19.44%	48.34%	-4.10%	48.94%	-423.21%	92.87%	74.52%	NA	NA	-53.85%	-42.08%	100.00%
		1i TO 4o	WIN91	18.30%	85.11%	-299.63%	0.00%	-18.29%	38.90%	68.08%	-20.22%	98.36%	97.33%	NA	NA	83.03%	70.52%	100.00%
		AVG-1,2,3	WIN91	22.58%	29.16%	27.86%	12.84%	-103.29%	32.60%	25.68%	58.38%	71.43%	86.95%	90.16%	-261.11%	84.60%	79.82%	99.95%
MEAN VALUES		Inflows	WIN91	11.01	232.96	3.23	7.41	2.56	431.33	330.76	110.67	7.26	19.55	7.99	0.07	260.74	39.37	40000.00
		Outflows	WIN91	8.84	131.79	5.24	6.82	158.01	265.79	189.10	76.69	1.08	1.35	0.37	0.09	26.51	8.09	22.22

Table 8. *Mean Values for Sampling Sites by Season for 1992.*

SPRING 1992

ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	8	7.74	1.85	13.65	261	4.05	7.44	139	459	309	150	9.70	24.42	5.94	0.13	457	46	22050
1i	6	7.74	1.85	12.58	219	2.83	7.28	-95	455	312	143	9.39	26.84	6.77	0.07	346	42	14400
1o	8	7.74	1.85	10.47	152	1.26	6.43	110	274	219	54	3.39	5.20	0.43	0.04	20	10	5
2a	6	7.74	1.85	9.73	157	0.78	8.65	NA	349	280	69	7.07	20.45	2.21	0.47	90	12	5
2b	8	7.74	1.85	10.05	174	1.21	8.51	NA	311	259	52	5.86	8.20	0.53	0.54	27	7	0
2c	8	7.74	1.85	9.63	148	1.58	6.46	NA	284	242	42	4.99	5.87	0.39	0.37	28	7	200
2i	6	7.74	1.85	12.62	226	3.00	7.20	-109	446	315	131	9.90	28.67	6.88	0.06	357	37	18225
2o	8	7.74	1.85	10.78	160	1.90	6.43	13	247	228	27	3.44	4.16	0.09	0.08	65	5	0
3i	6	7.74	1.85	12.24	268	3.65	7.11	-169	450	325	125	9.78	31.24	6.87	0.09	336	37	19667
3o	8	7.74	1.85	10.54	176	1.57	6.36	-88	286	260	25	5.88	7.62	0.25	0.85	61	6	0
4o	6	7.74	1.85	12.67	132	5.35	7.13	139	193	173	20	0.43	1.08	0.05	0.04	22	7	400
REDUCTION %		CELL 1	SPR92	16.77%	30.39%	55.48%	11.68%	216.73%	39.89%	29.79%	62.07%	63.90%	80.63%	93.65%	42.86%	94.33%	75.43%	99.97%
		CELL 2	SPR92	14.58%	29.26%	36.67%	10.69%	112.07%	44.62%	27.55%	79.21%	65.25%	85.49%	98.69%	-33.33%	81.78%	87.62%	100.00%
		CELL 3	SPR92	13.89%	34.28%	56.99%	10.55%	47.87%	36.52%	19.83%	79.74%	39.88%	75.61%	96.36%	-844.44%	81.93%	84.33%	100.00%
		CELL 4	SPR92	-21.01%	13.13%	-324.60%	-10.89%	-25.91%	29.37%	20.99%	63.08%	87.32%	79.23%	88.37%	0.00%	-12.05%	30.24%	-7900.00%
		1I TO 4O	SPR92	-30.37%	-71.45%	-221.43%	-15.71%	-25.46%	-67.70%	-40.99%	-176.30%	-186.14%	-369.62%	-1281.40%	-225.00%	-2231.14%	-346.05%	-440900.00%
		AVG-1,2,3	SPR92	15.08%	31.31%	49.71%	10.97%	125.56%	40.34%	25.72%	73.68%	56.34%	80.57%	96.23%	-278.31%	86.01%	82.46%	99.99%
MEAN VALUES		Inflows	SPR92	12.48	237.80	3.16	7.20	-124.20	450.40	317.38	133.02	9.69	28.92	6.84	0.07	346.06	38.66	17430.56
		Outflows	SPR92	10.60	162.91	1.58	8.41	11.78	268.77	235.97	35.59	4.24	5.66	0.26	0.32	48.43	6.89	1.67

SUMMER 1992

ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	7	7.33	1.79	25.84	437.43	4.33	6.85	-21	689	405	284	9.33	12.51	2.69	0.05	620	49	15175
1i	7	7.33	1.79	23.47	412.67	3.35	6.82	-145	615	385	230	9.42	12.41	3.56	0.05	477	35	18767
1o	7	7.33	1.79	21.52	334.50	1.33	5.97	-75	376	330	46	4.34	6.88	0.53	0.04	37	9	1167
2a	7	7.33	1.79	20.83	412.43	1.16	8.07	NA	568	373	195	8.88	11.33	6.77	0.06	147	29	3233
2b	7	7.33	1.79	20.27	356.86	1.16	6.13	NA	476	355	122	8.13	10.49	1.91	0.03	116	19	600
2c	7	7.33	1.79	19.86	304.00	1.20	5.96	NA	403	324	79	6.39	8.88	0.15	0.02	92	12	384
2i	7	7.33	1.79	24.11	435.29	3.22	6.71	-137	570	414	153	9.26	12.01	3.35	0.05	352	32	14060
2o	7	7.33	1.79	21.21	281.14	1.31	6.00	-119	310	263	47	5.07	6.33	0.16	0.02	16	6	181
3i	7	7.33	1.79	23.63	411.00	3.62	6.73	-174	639	393	246	9.87	12.59	3.35	0.05	414	43	13760
3o	7	7.33	1.79	20.73	296.67	1.14	5.90	-67	366	336	30	6.71	7.65	1.32	0.03	22	7	668
4o	7	7.33	1.79	20.7	258.50	2.18	6.73	-134	342	280	62	0.13	1.94	0.7	0.02	39	14	234
REDUCTION %		CELL 1	SUM92	8.31%	18.94%	60.30%	12.46%	48.04%	38.90%	14.41%	79.97%	53.93%	44.56%	85.11%	20.00%	92.20%	73.59%	93.78%
		CELL 2	SUM92	12.03%	35.41%	59.32%	10.58%	13.59%	45.58%	36.51%	69.19%	45.25%	47.29%	95.22%	60.00%	95.32%	82.86%	98.71%
		CELL 3	SUM92	12.27%	27.82%	68.51%	12.33%	61.68%	42.69%	14.61%	87.61%	32.02%	39.24%	60.60%	40.00%	94.80%	83.11%	95.14%
		CELL 4	SUM92	3.81%	22.72%	-63.91%	-12.73%	-78.60%	8.96%	15.07%	-34.78%	97.00%	71.80%	-32.08%	50.00%	-3.85%	-54.12%	79.99%
		1i to 4o	SUM92	11.80%	37.36%	34.93%	1.32%	7.20%	44.37%	27.30%	73.00%	98.62%	84.37%	80.34%	60.00%	91.90%	59.30%	98.76%
		AVG-1,2,3	SUM92	10.87%	27.39%	62.71%	11.79%	41.10%	42.39%	21.84%	78.92%	43.73%	43.70%	80.31%	40.00%	94.11%	79.85%	95.88%
MEAN VALUES		Inflows	SUM92	23.74	419.65	3.40	6.75	-151.93	607.72	397.39	209.45	9.52	12.34	3.42	0.05	414.05	36.66	15528.89
		Outflows	SUM92	21.14	291.38	1.61	6.23	-109.36	342.56	290.84	51.71	3.18	5.05	0.46	0.03	30.74	9.55	527.06

FALL 1992

ST	N	GAGE	RAIN	TEMP	COND	DO	PH	RED	TS	DS	SS	FOP	TP	NH3	NO3	CHL	BOD	COL
LG	6	6.76	2.63	23.62	539	2.27	6.82	-65.73	594.67	450.83	143.83	10.22	12.92	10.83	0.07	190.35	35.72	12100
1i	6	6.76	2.63	22.8	527.33	3.91	7	38	525	459	65	10.74	11.98	11.57	0.06	100	24	1533
1o	6	6.76	2.63	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2a	6	6.76	2.63	20.07	402.67	2.24	6.46	NA	512	413	102	9.96	11.32	8.64	0.06	54	17	415
2b	6	6.76	2.63	20.07	470.67	2.75	6.26	NA	502	387	120	8.76	9.73	4.5	0.04	60	13	225
2c	6	6.76	2.63	19.6	413.17	2.2	6.11	NA	575	463	199	6.8	8.33	1.04	0.05	108	18	85
2i	6	6.76	2.63	24.38	566.33	3.74	7.09	-107	485	428	57	9.88	14.89	11.28	0.06	74	26	2359
2o	6	6.76	2.63	21.57	400.17	2.92	6.16	-62	354	310	61	6.06	6.82	0.5	0.05	24	5	2725
3i	6	8.76	2.63	23.82	540.33	4	6.95	-112	527	469	58	10.02	11.99	11.42	0.09	61	23	6725
3o	6	6.76	2.63	21.73	499.17	3.35	6.24	-28	381	357	24	7.67	8.53	2.97	0.05	31	6	690
4o	6	6.76	2.63	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
REDUCTION %		CELL 1	FALL 92	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		CELL 2	FALL 92	11.53%	29.34%	21.93%	13.12%	41.93%	26.98%	27.62%	-6.46%	38.66%	54.20%	95.57%	16.67%	68.07%	78.84%	-15.54%
		CELL 3	FALL 92	8.77%	7.62%	16.25%	10.22%	75.37%	27.76%	24.04%	57.93%	23.45%	28.86%	73.99%	44.44%	49.22%	76.15%	89.74%
		AVG-1,2,3	FALL 92	10.15%	18.48%	19.09%	11.67%	58.65%	27.37%	25.83%	25.74%	31.06%	41.53%	84.78%	30.56%	58.65%	77.49%	37.10%
MEAN VALUES		Inflows	FALL 92	23.67	544.66	3.88	7.01	-60.53	512.22	452.22	60.00	10.21	12.95	11.42	0.07	78.21	24.22	3538.83
		Outflows	FALL 92	21.65	449.67	3.14	6.20	-44.91	367.42	333.15	42.42	6.87	7.68	1.74	0.05	27.29	5.46	1707.50

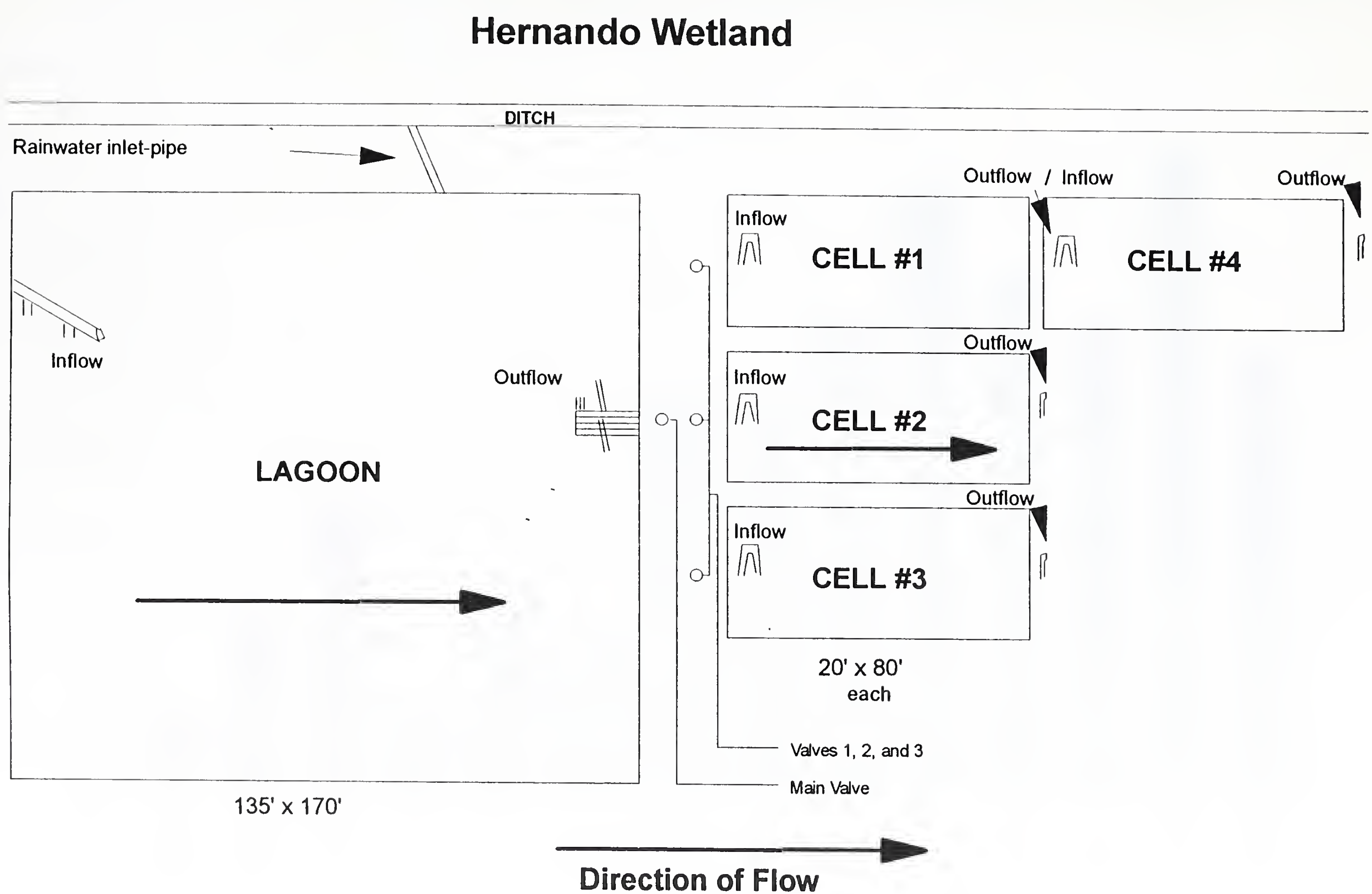

Figure 1. *Drawing of Lagoon/Wetland Cell Construction at Hernando Wetland on Allan Scott Farm, DeSoto County, Mississippi.*

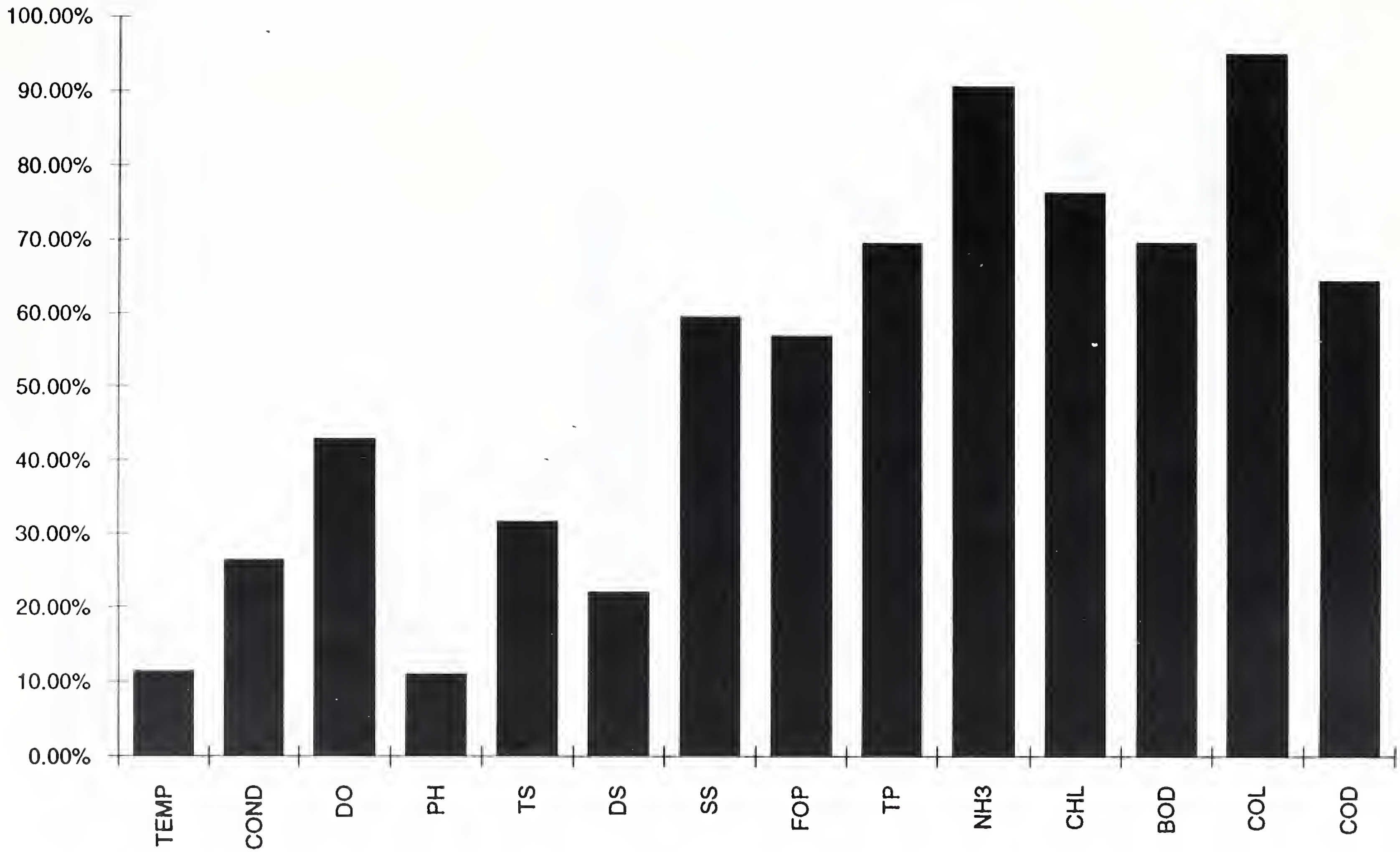

Figure 2. *Mean reduction percentages of routinely monitored parameters during the study period.*

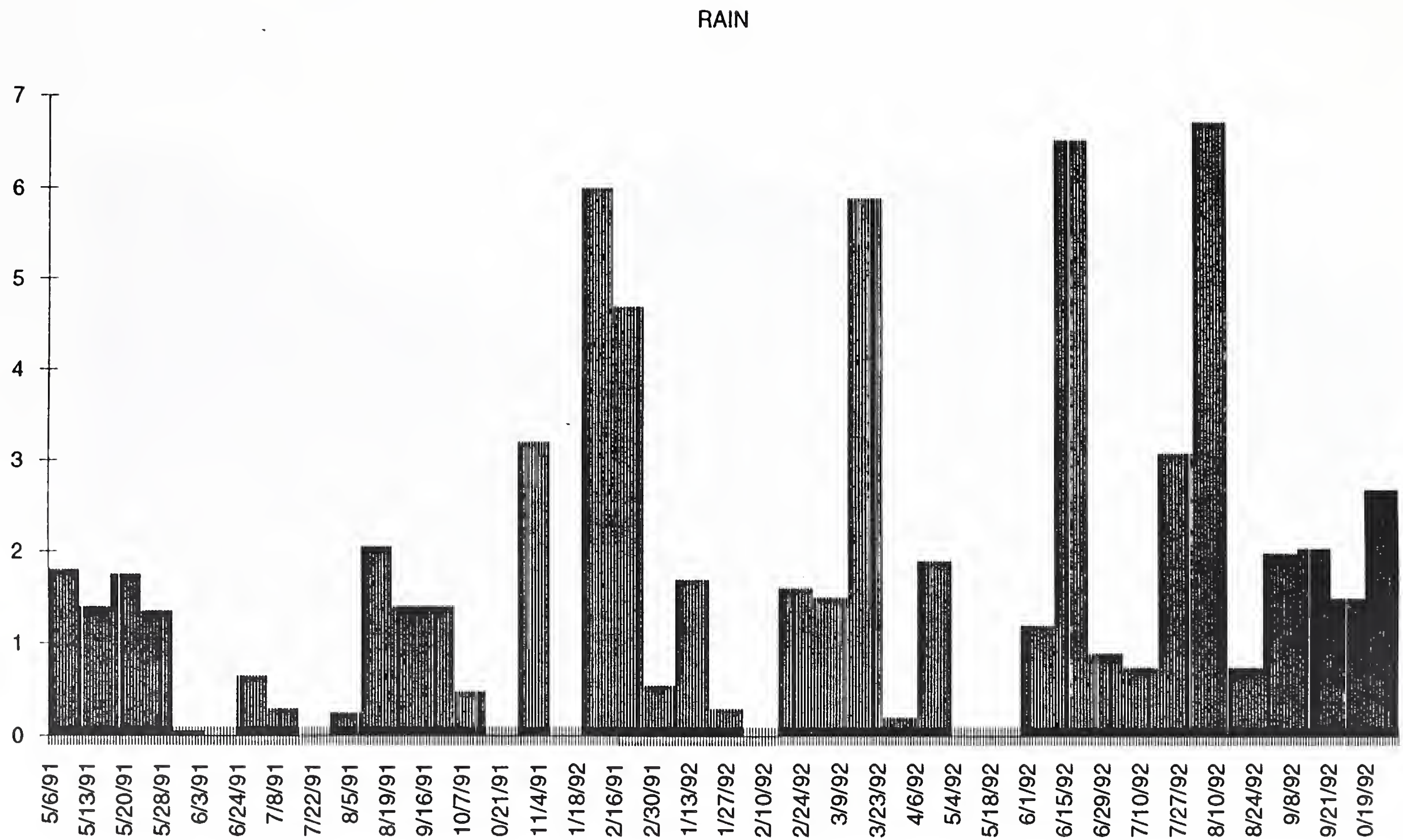

Figure 3. *Rainfall amounts during the study period.*

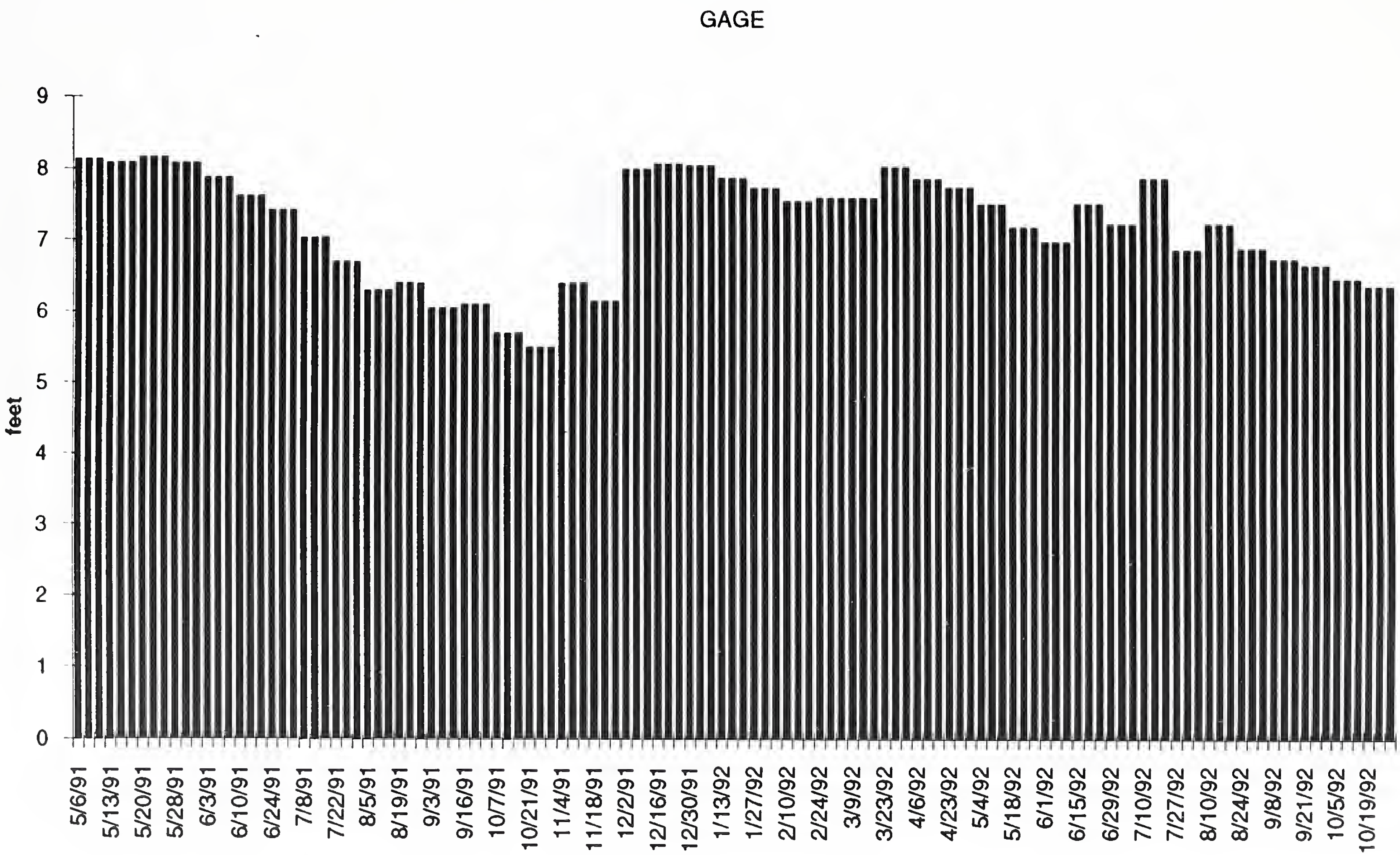

Figure 4. *Water depth in the primary settling lagoon during the study period.*

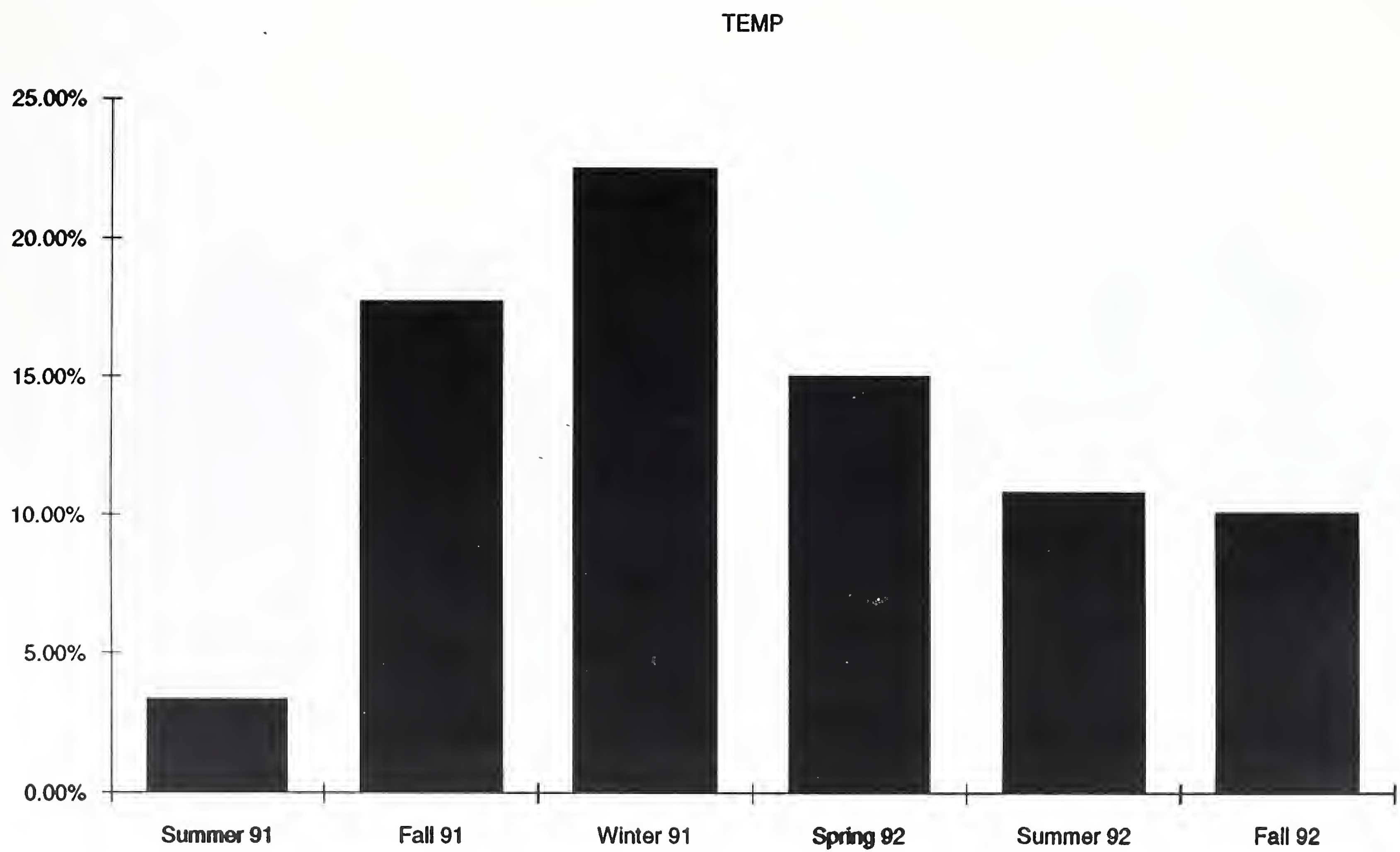

Figure 5. *Mean seasonal reduction of temperature in wetland cells.*

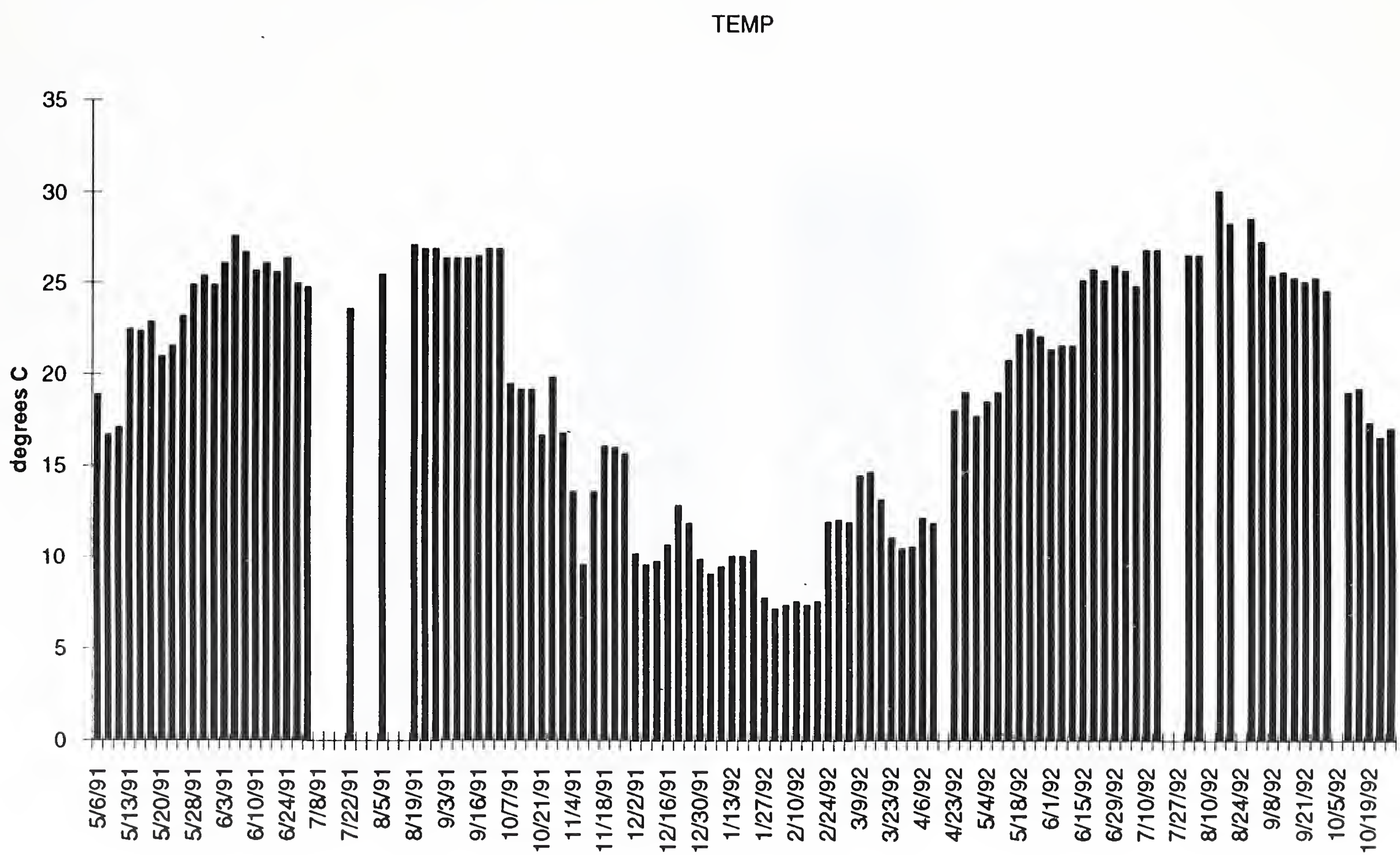

Figure 6. *Inflow station temperature values during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

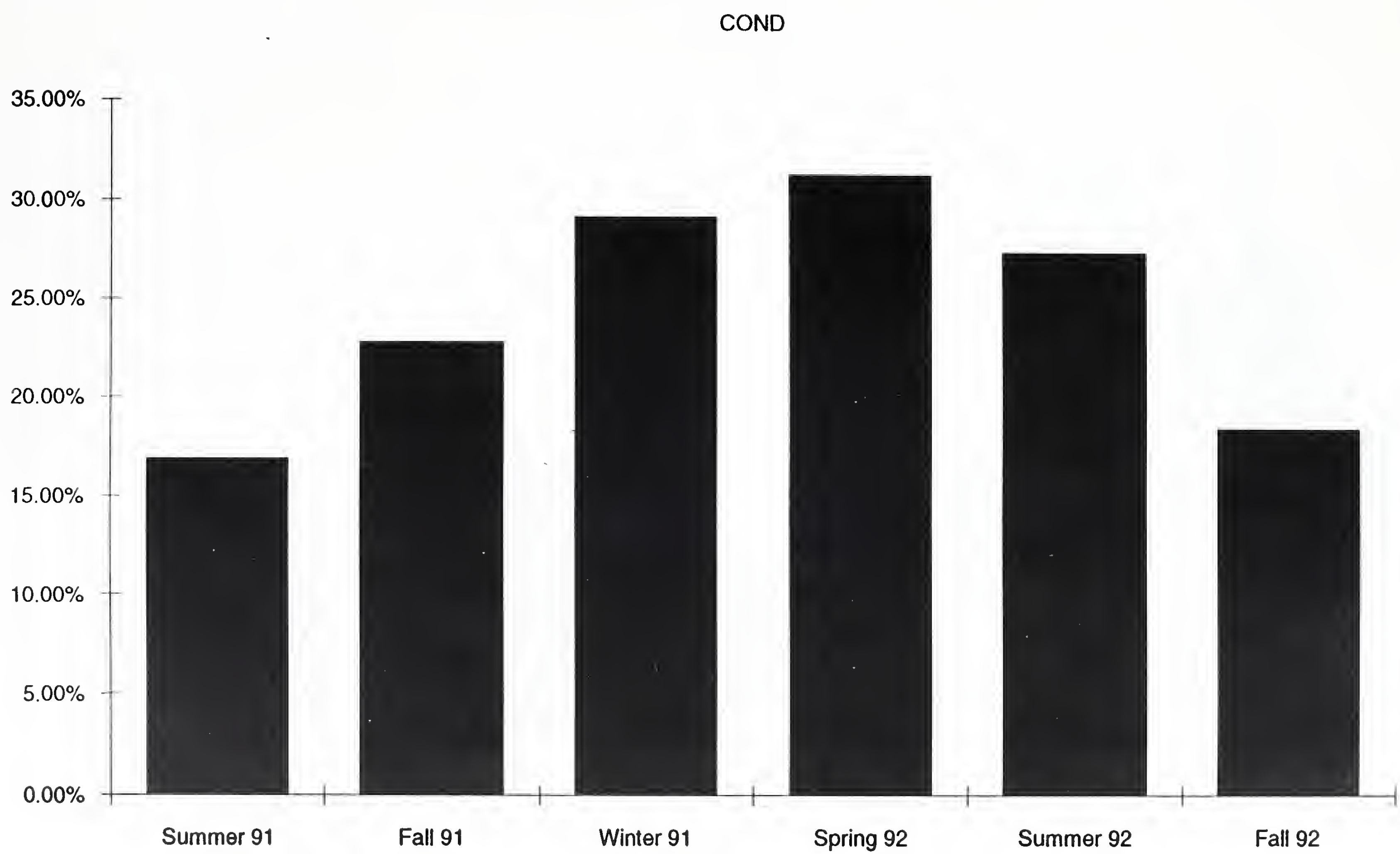

Figure 7. *Mean seasonal reduction of conductivity in wetland cells.*

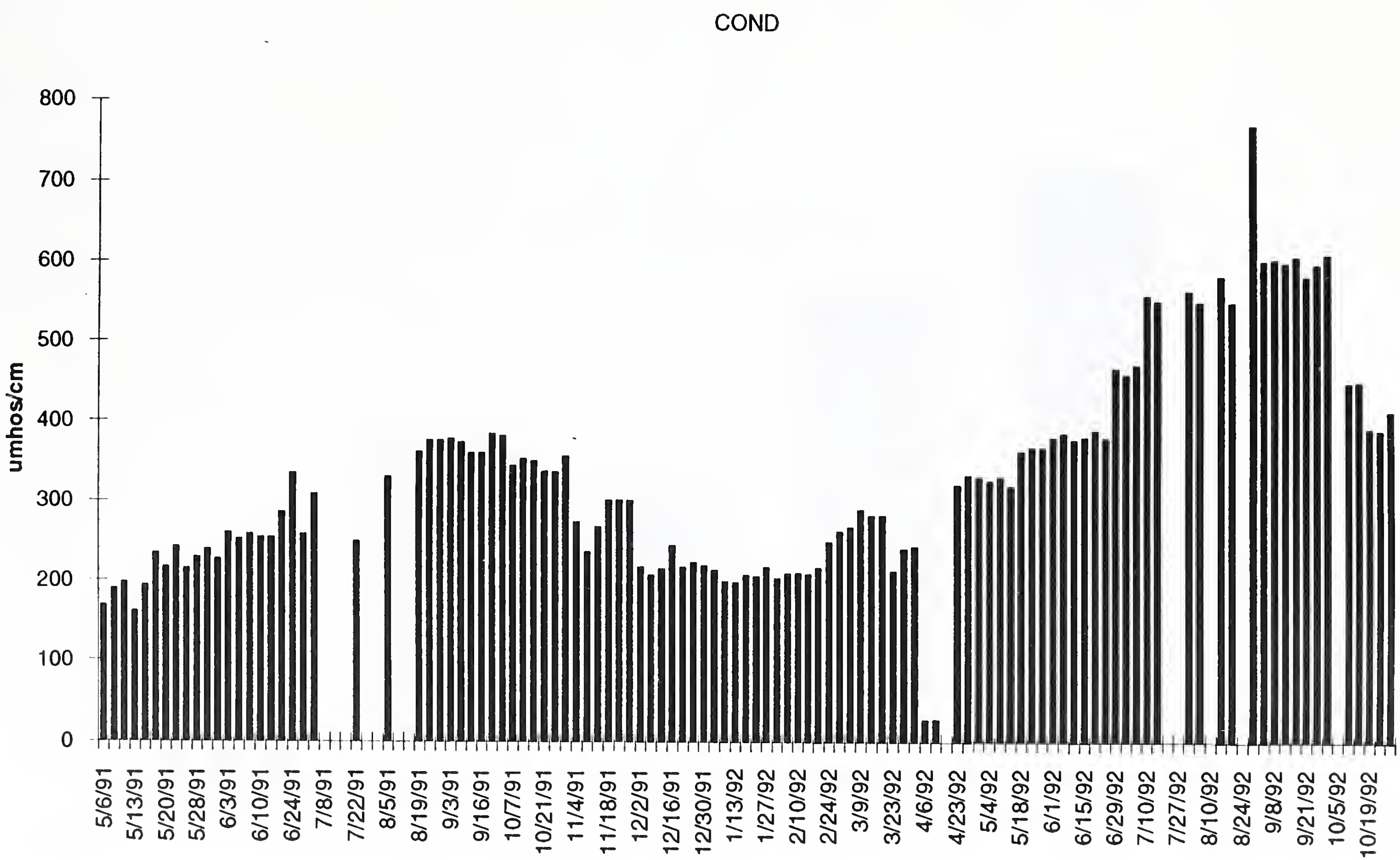

Figure 8. *Inflow station conductivity values during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

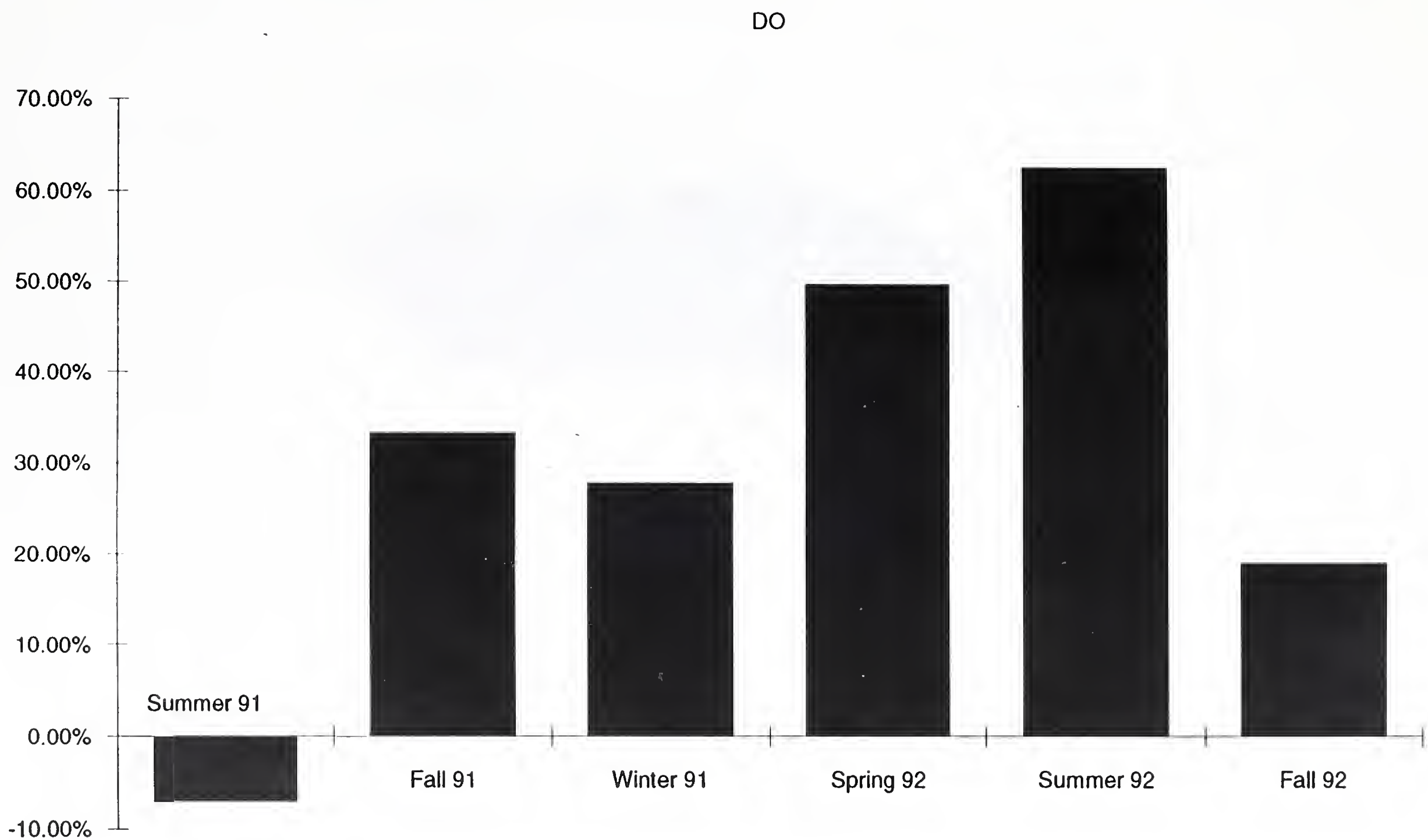

Figure 9. *Mean seasonal reduction of dissolved oxygen in wetland cells.*

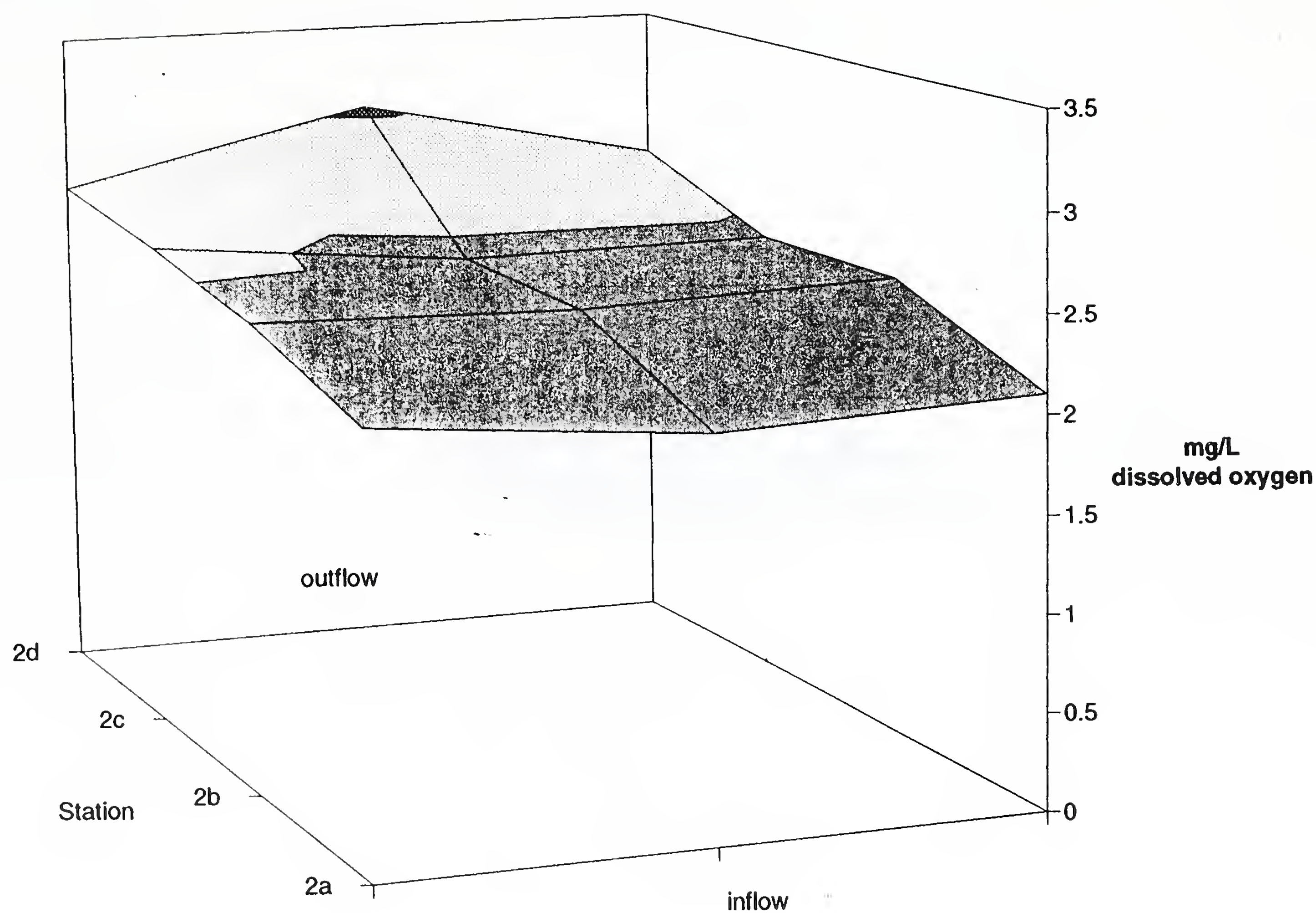

Figure 10. *Typical lower water column dissolved oxygen pattern in Cell 2.*

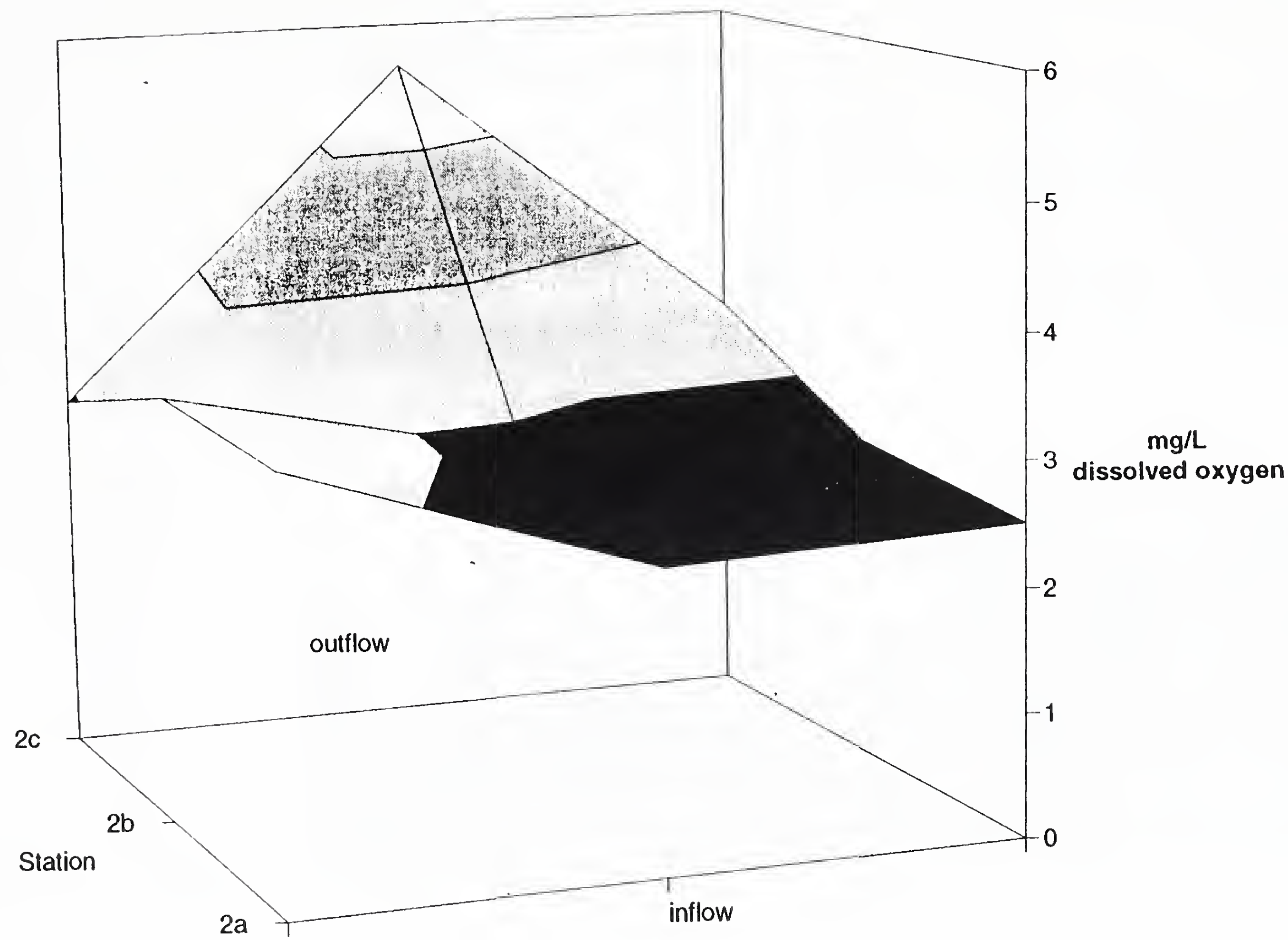

Figure 11. *Typical upper water column dissolved oxygen pattern in Cell 2.*

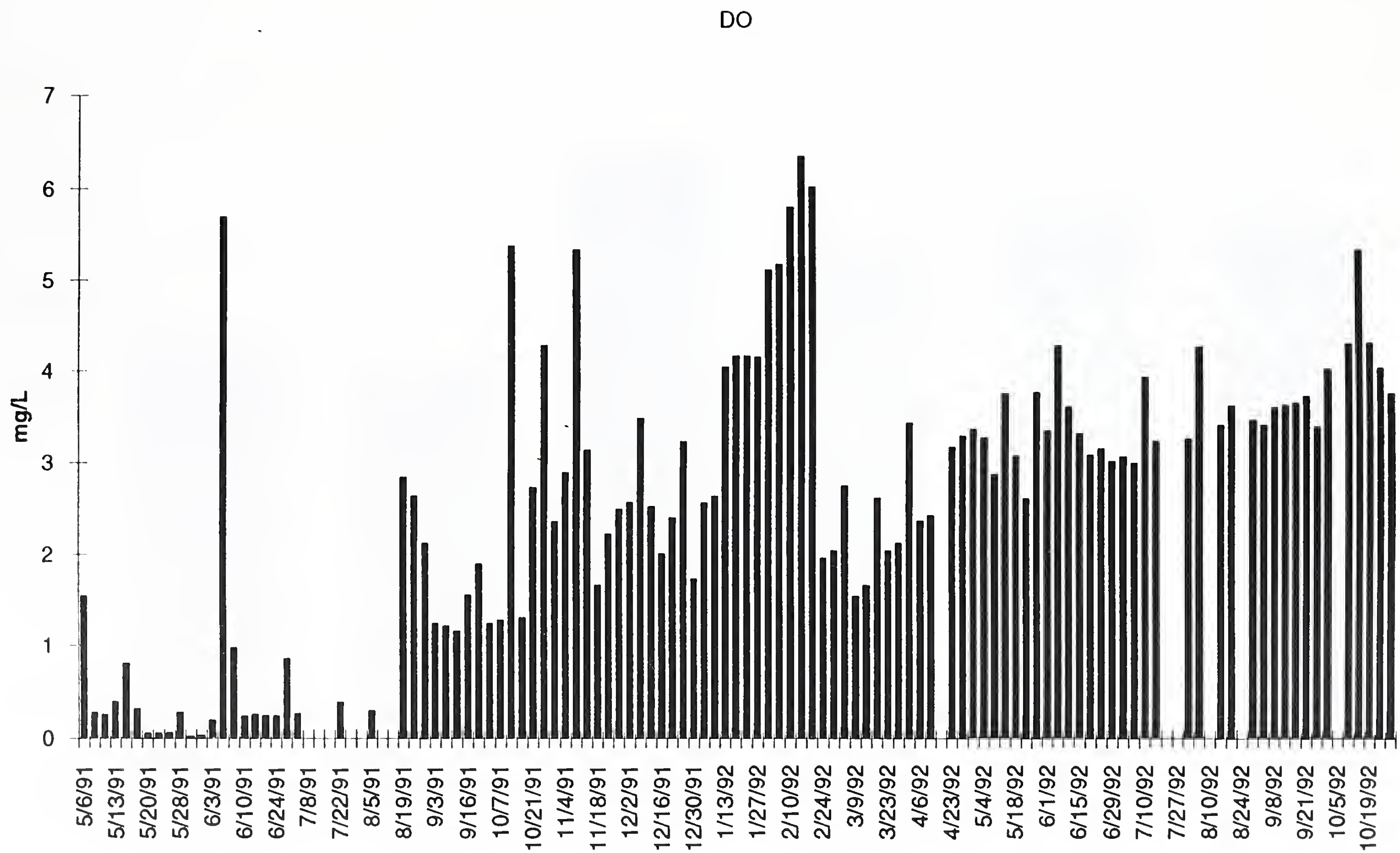

Figure 12. *Inflow station dissolved oxygen concentrations during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

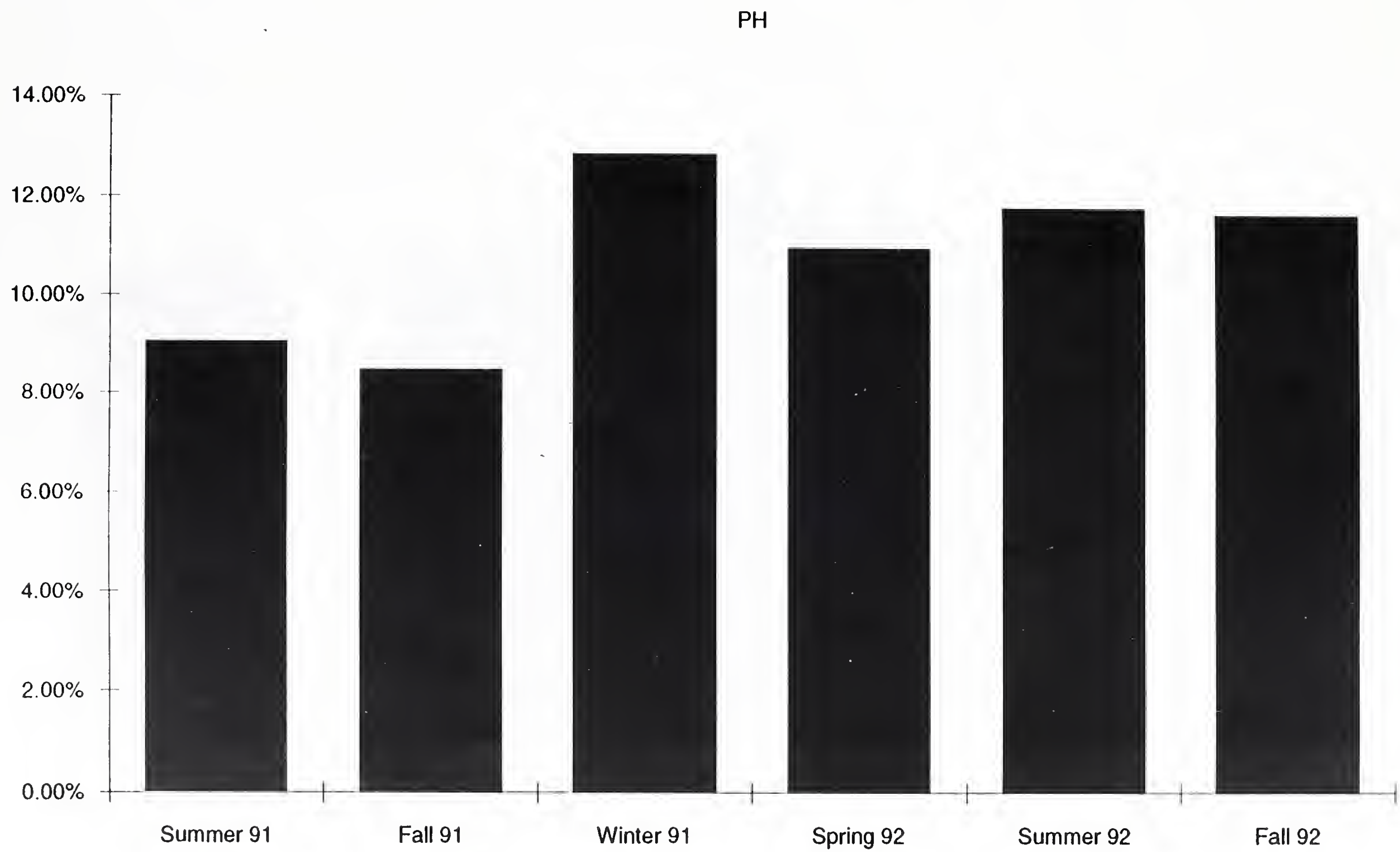

Figure 13. *Mean seasonal reduction of pH values in wetland cells.*

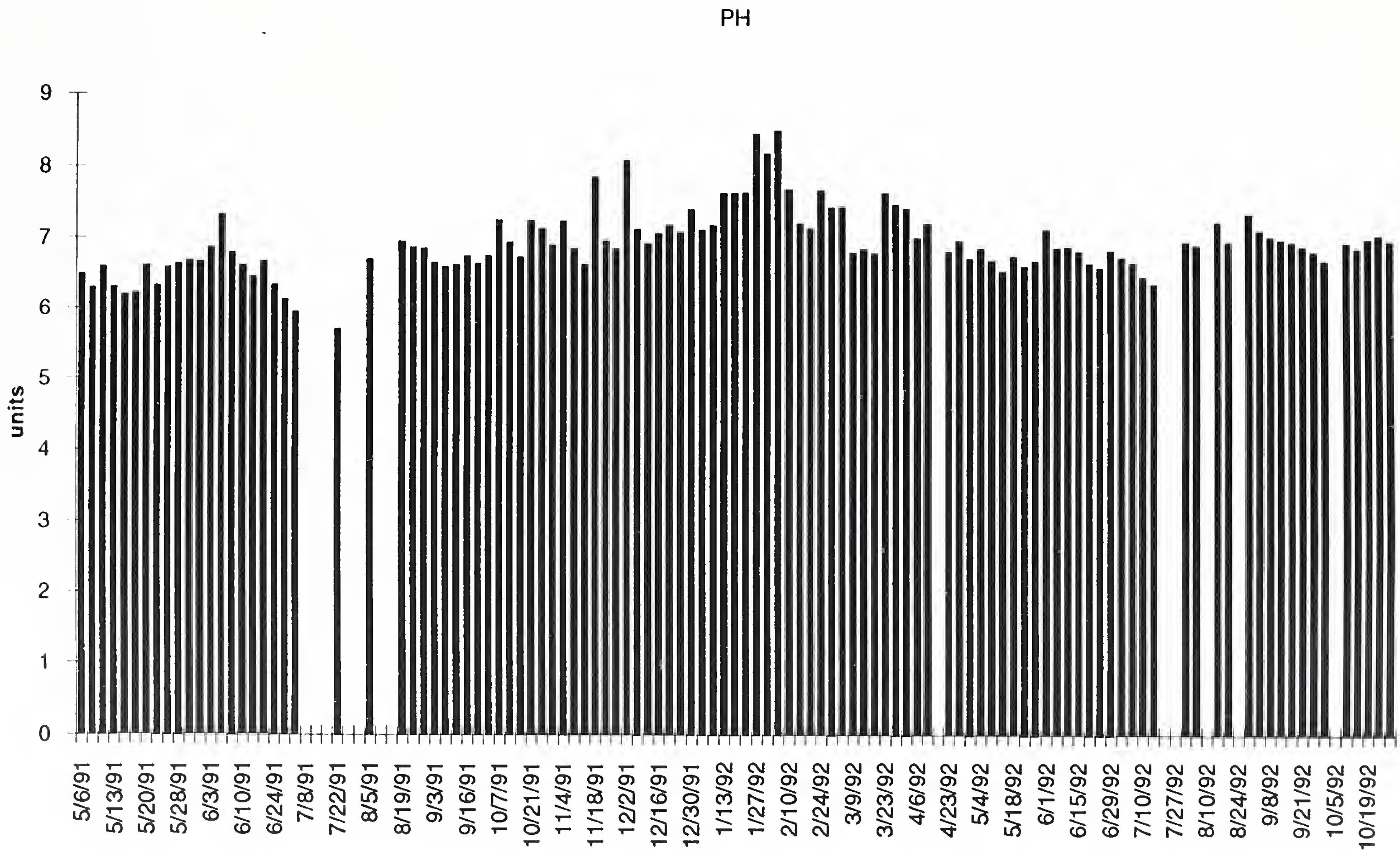

Figure 14. *Inflow station pH values during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

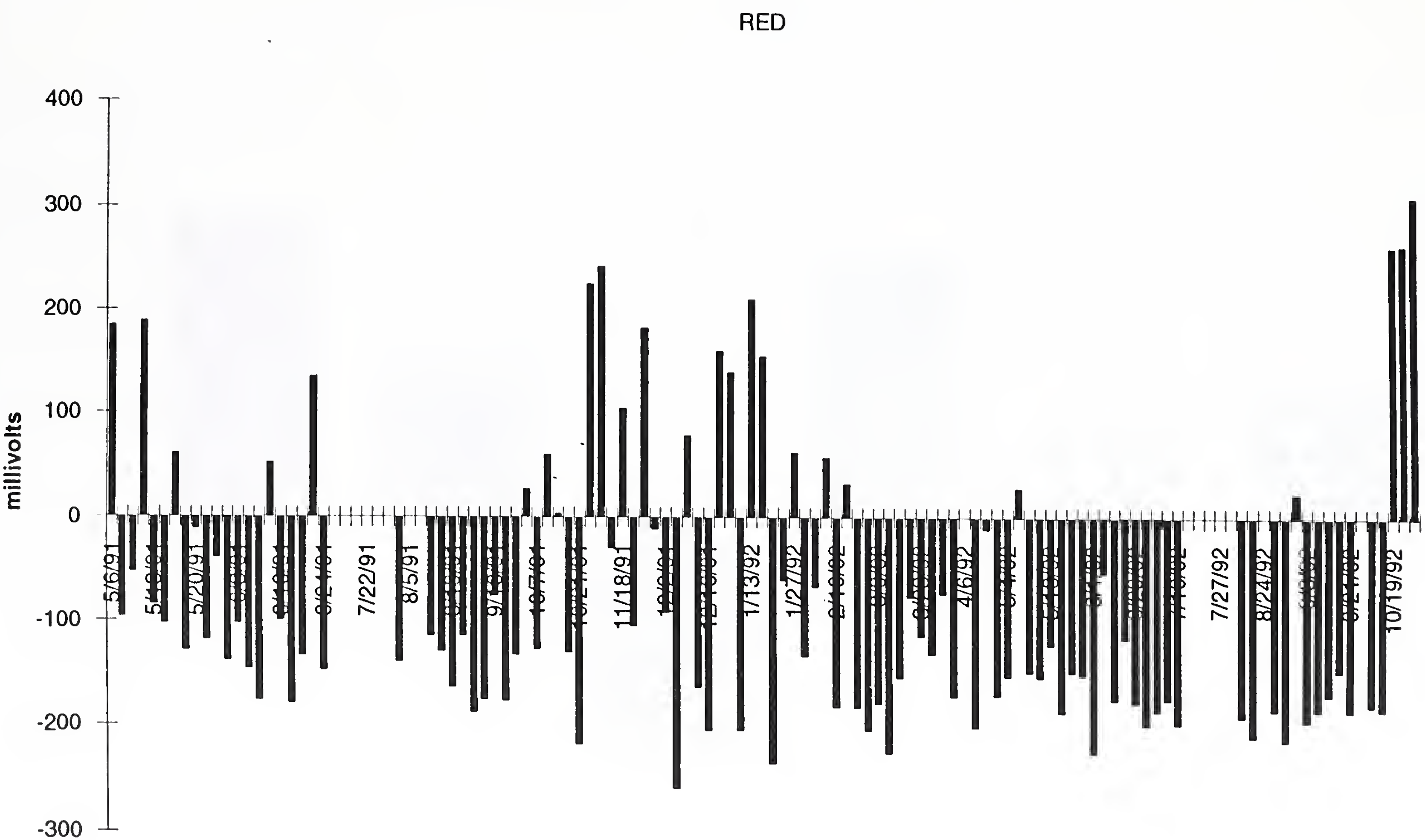

Figure 15. *Inflow station redox values during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

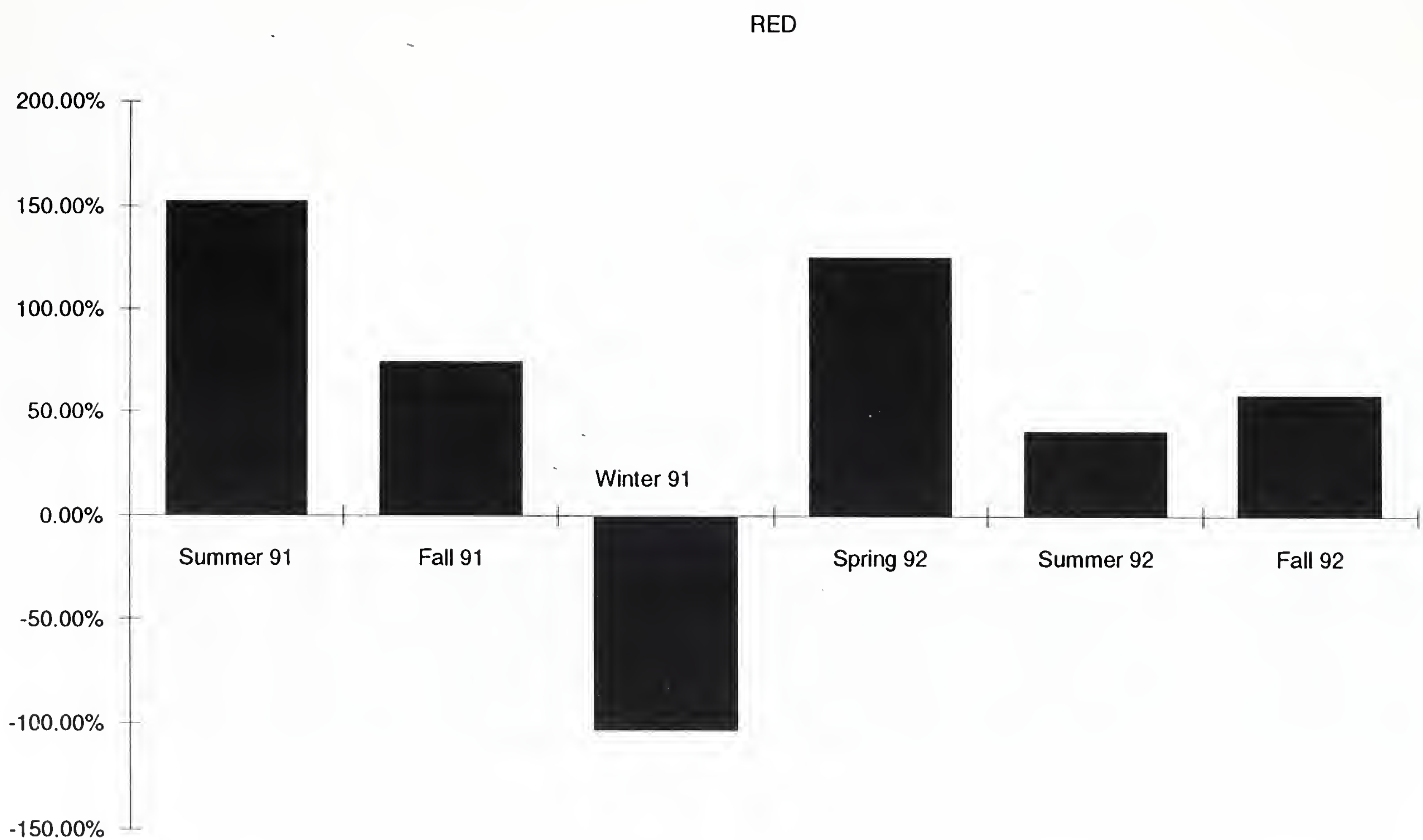

Figure 16. *Mean seasonal reduction of redox in wetland cells.*

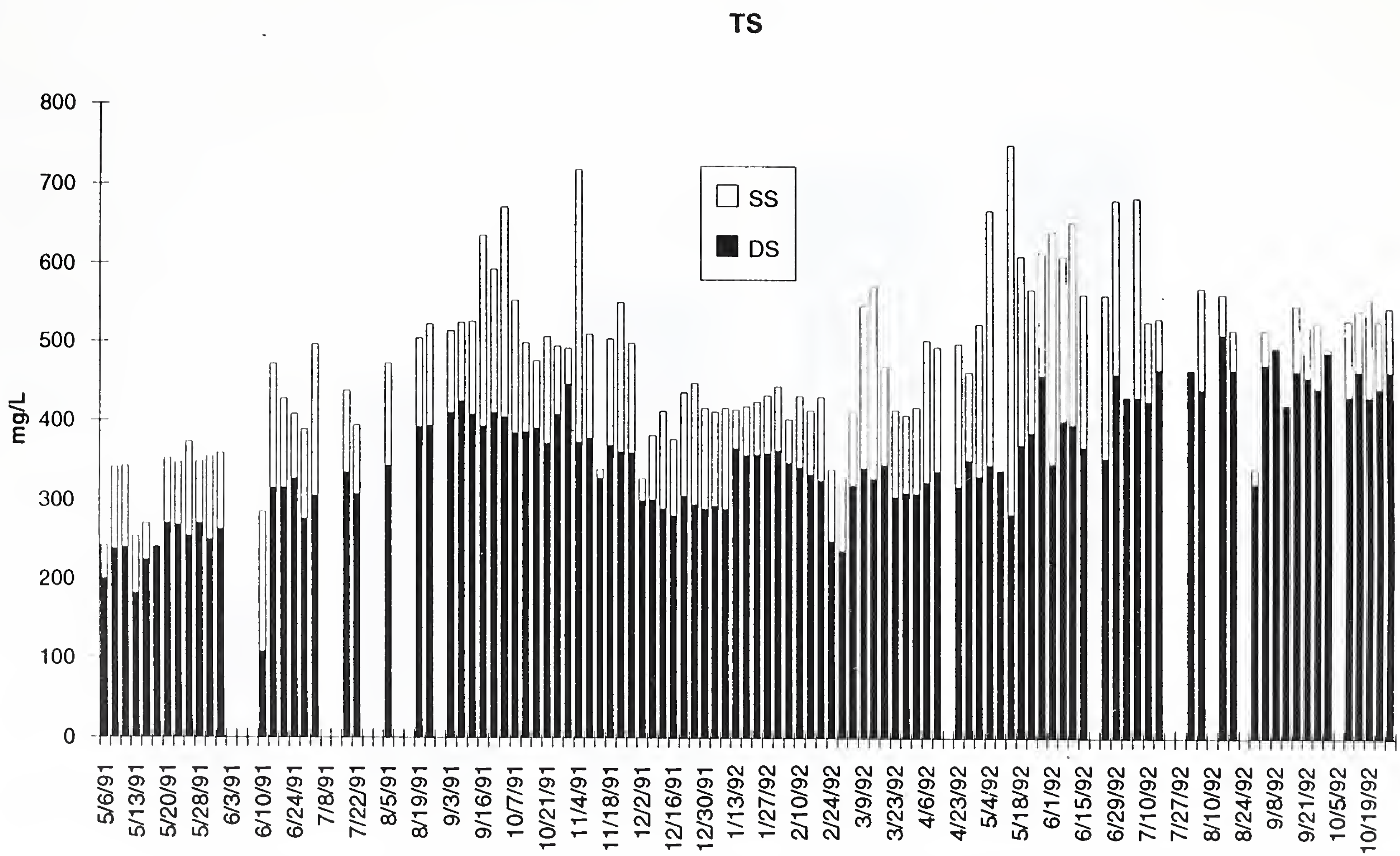

Figure 17. *Inflow station total solids concentrations during the study period showing dissolved and suspended component contributions.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

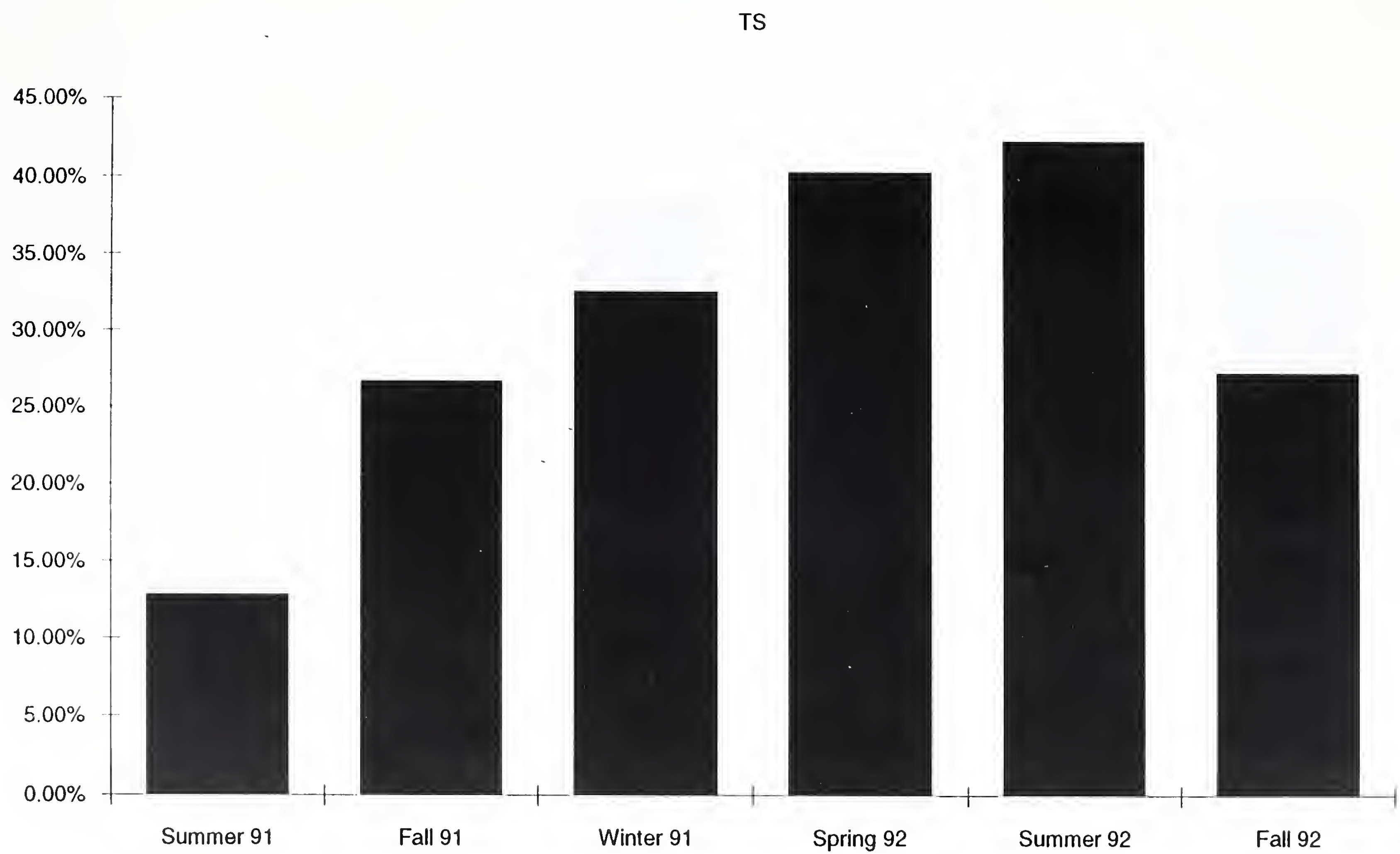

Figure 18. *Mean seasonal reductions of total solids in wetland cells.*

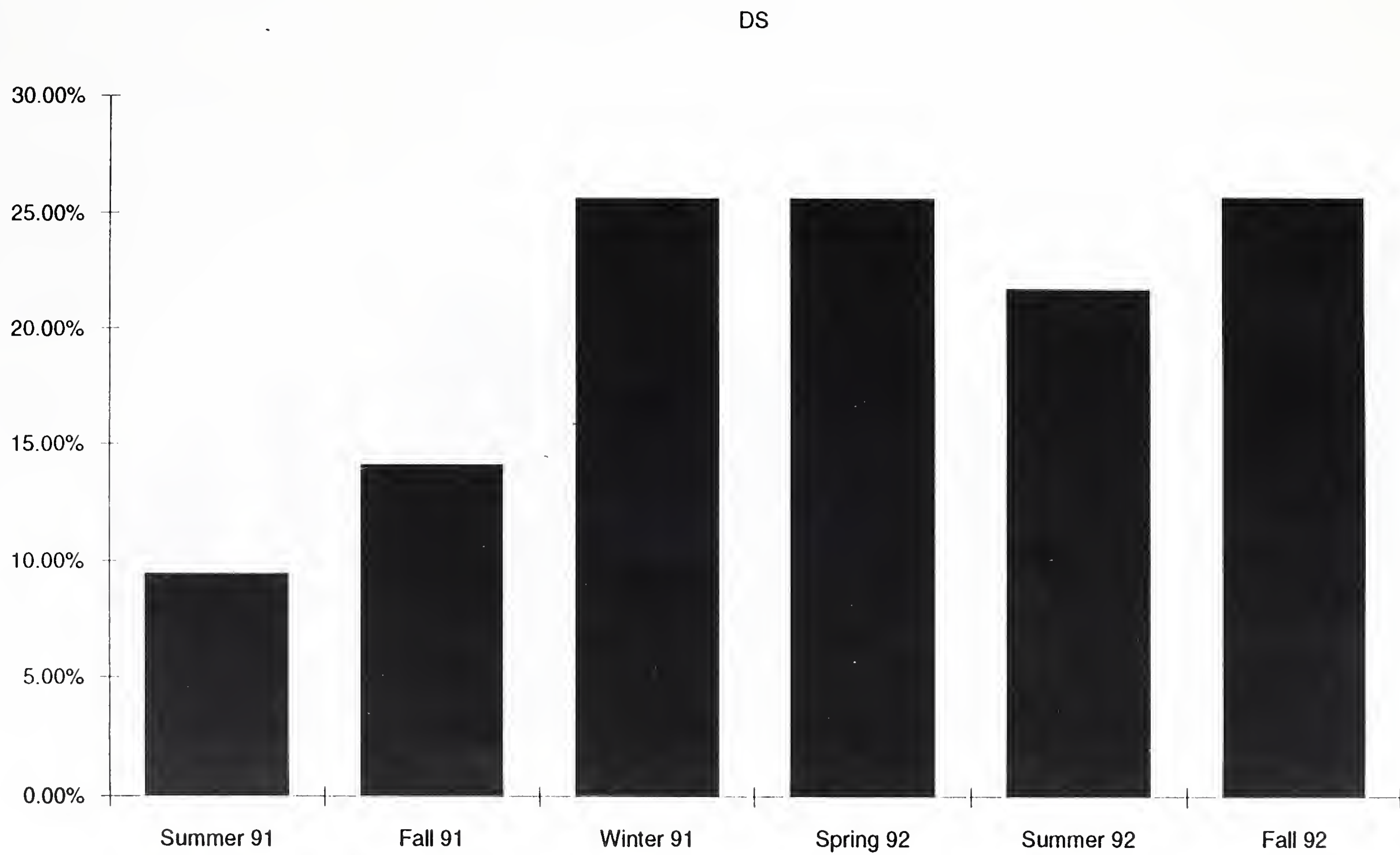

Figure 19. *Mean seasonal reductions of dissolved solids in wetland cells.*

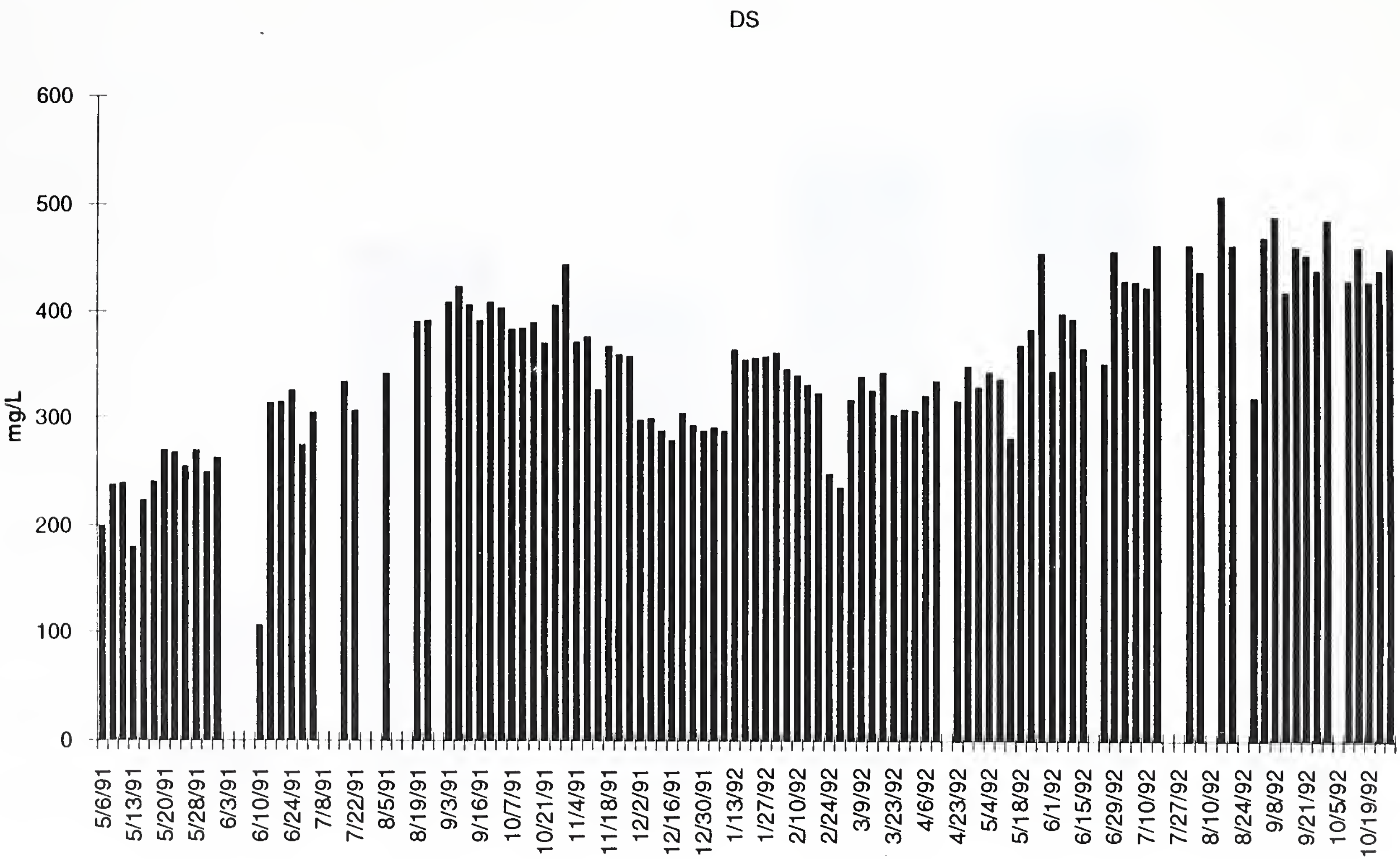

Figure 20. *Inflow station dissolved solids concentrations during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

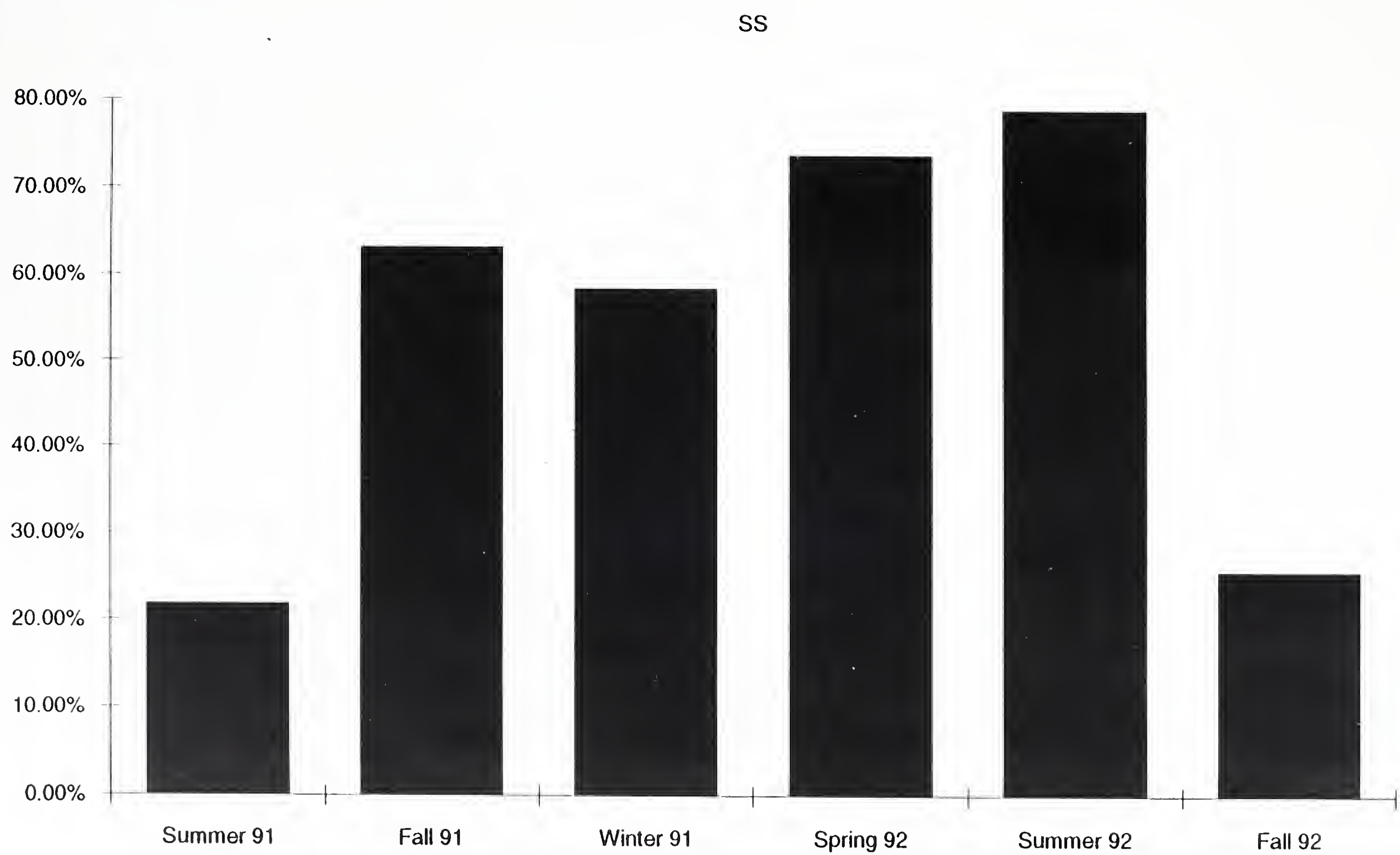

Figure 21. *Mean seasonal reduction of suspended solids in wetland cells.*

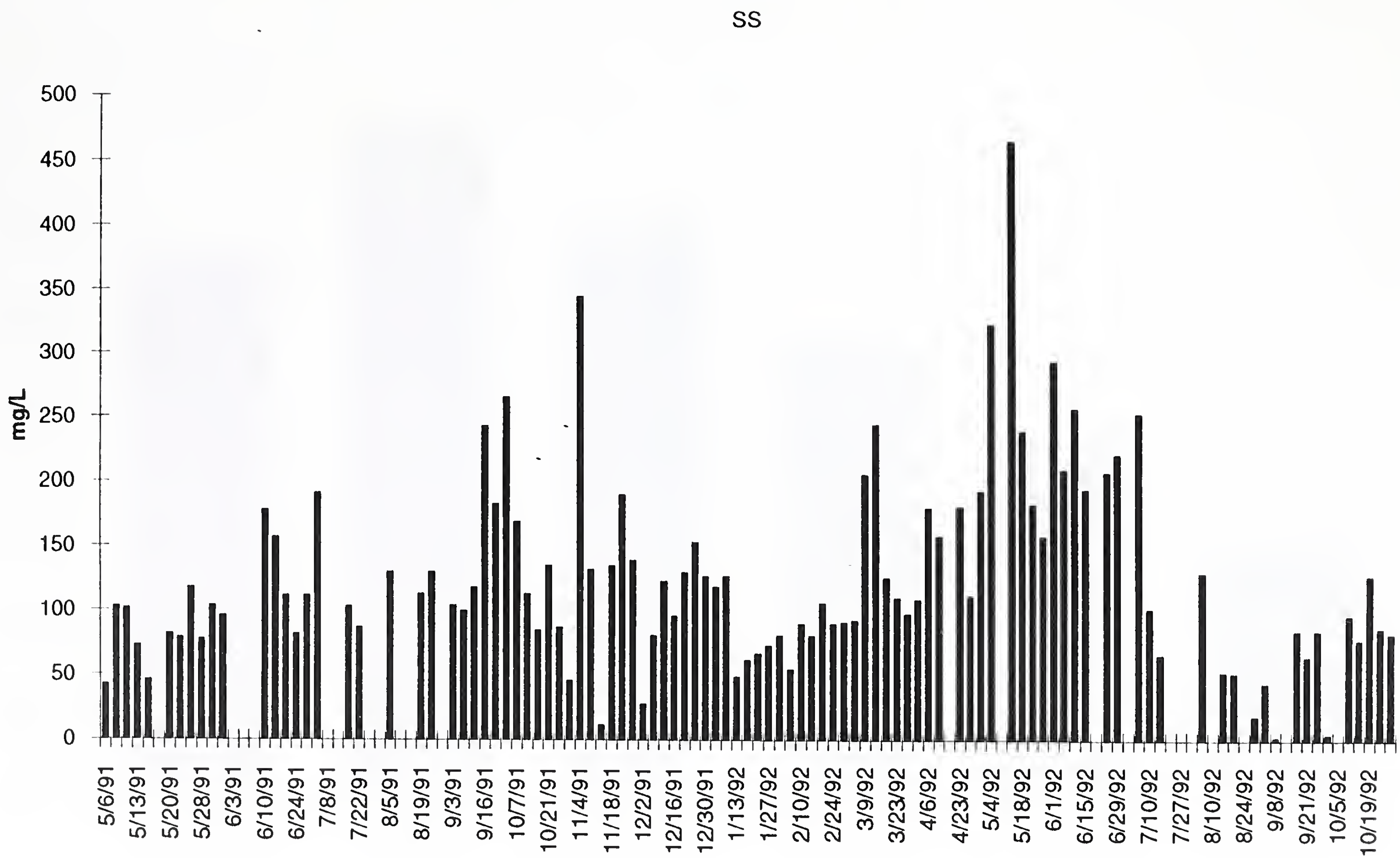

Figure 22. *Inflow station suspended solids concentration during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

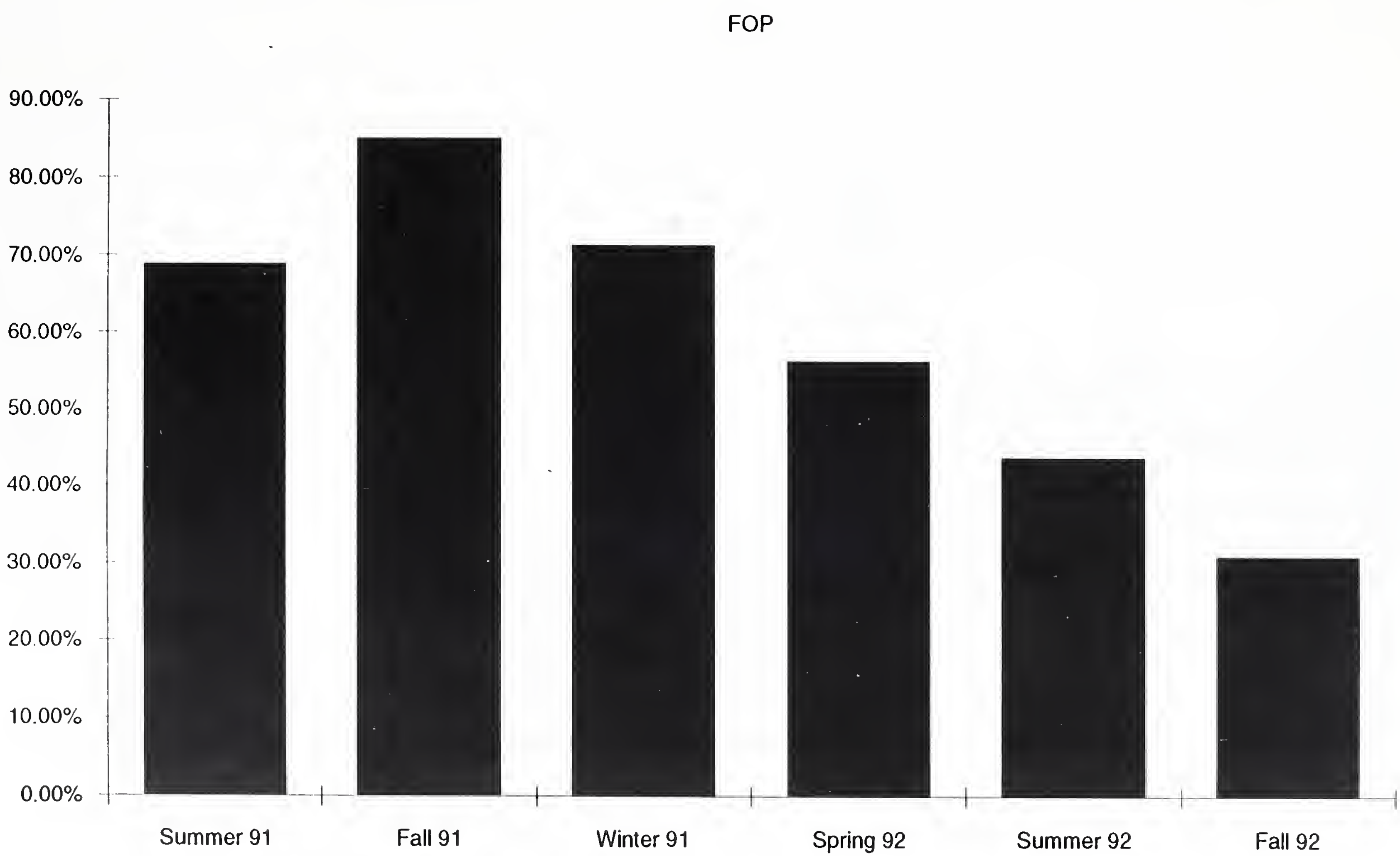

Figure 23. *Mean seasonal reduction of filterable ortho-phosphorus in wetland cells.*

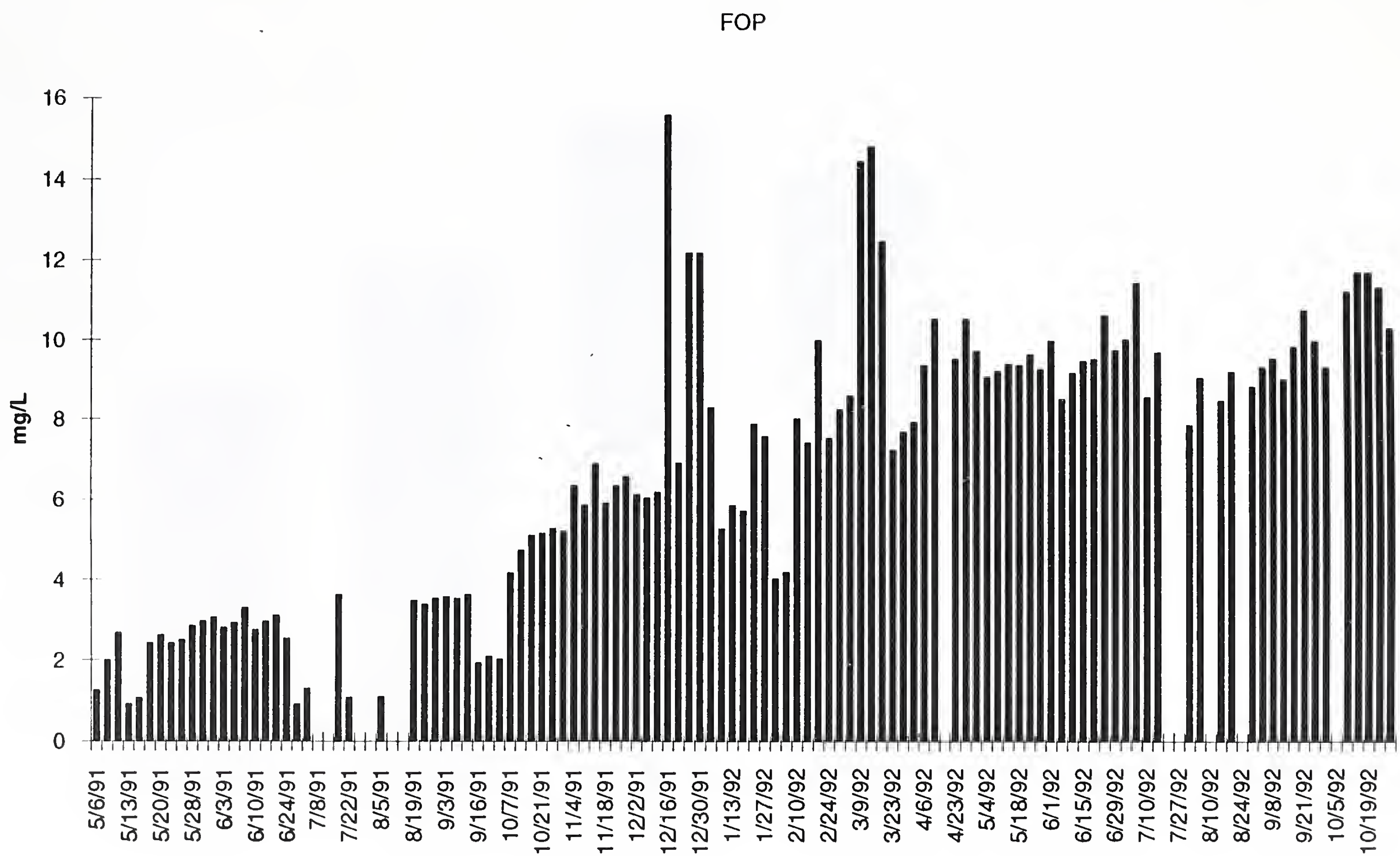

Figure 24. *Inflow station filterable ortho-phosphorus concentrations during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

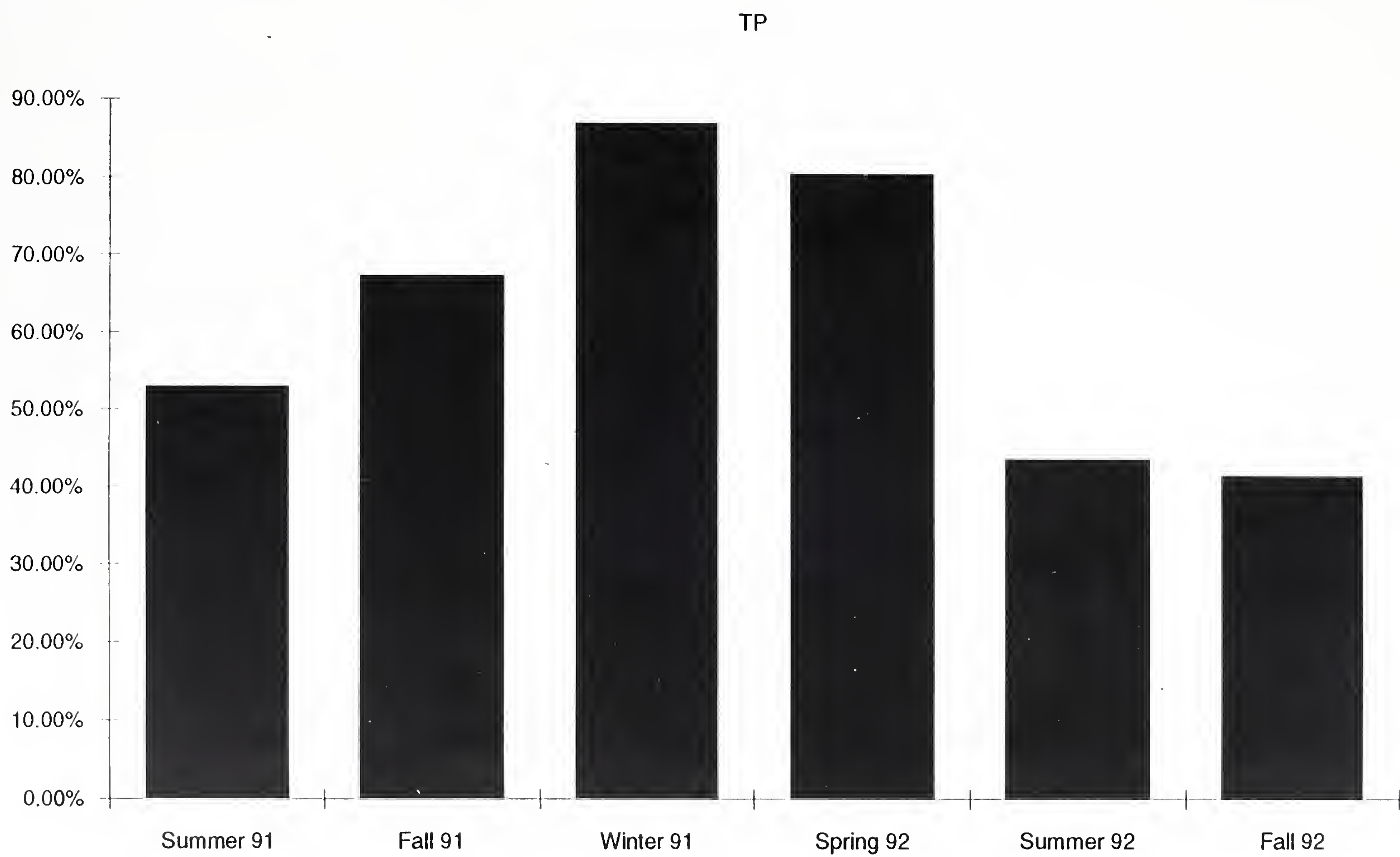

Figure 25. *Mean seasonal reduction of total phosphorus in wetland cells.*

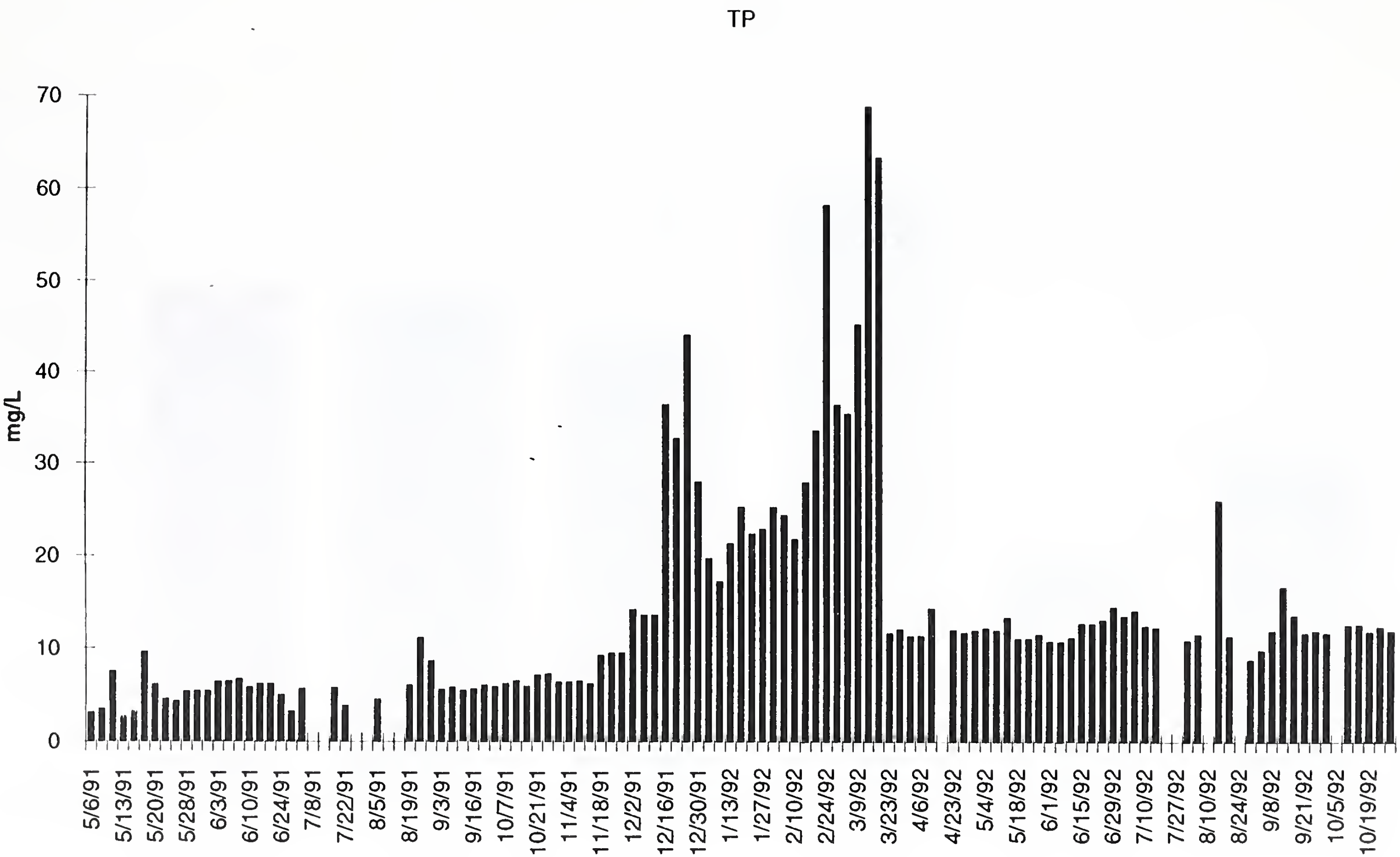

Figure 26. *Inflow station total phosphorus concentrations during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

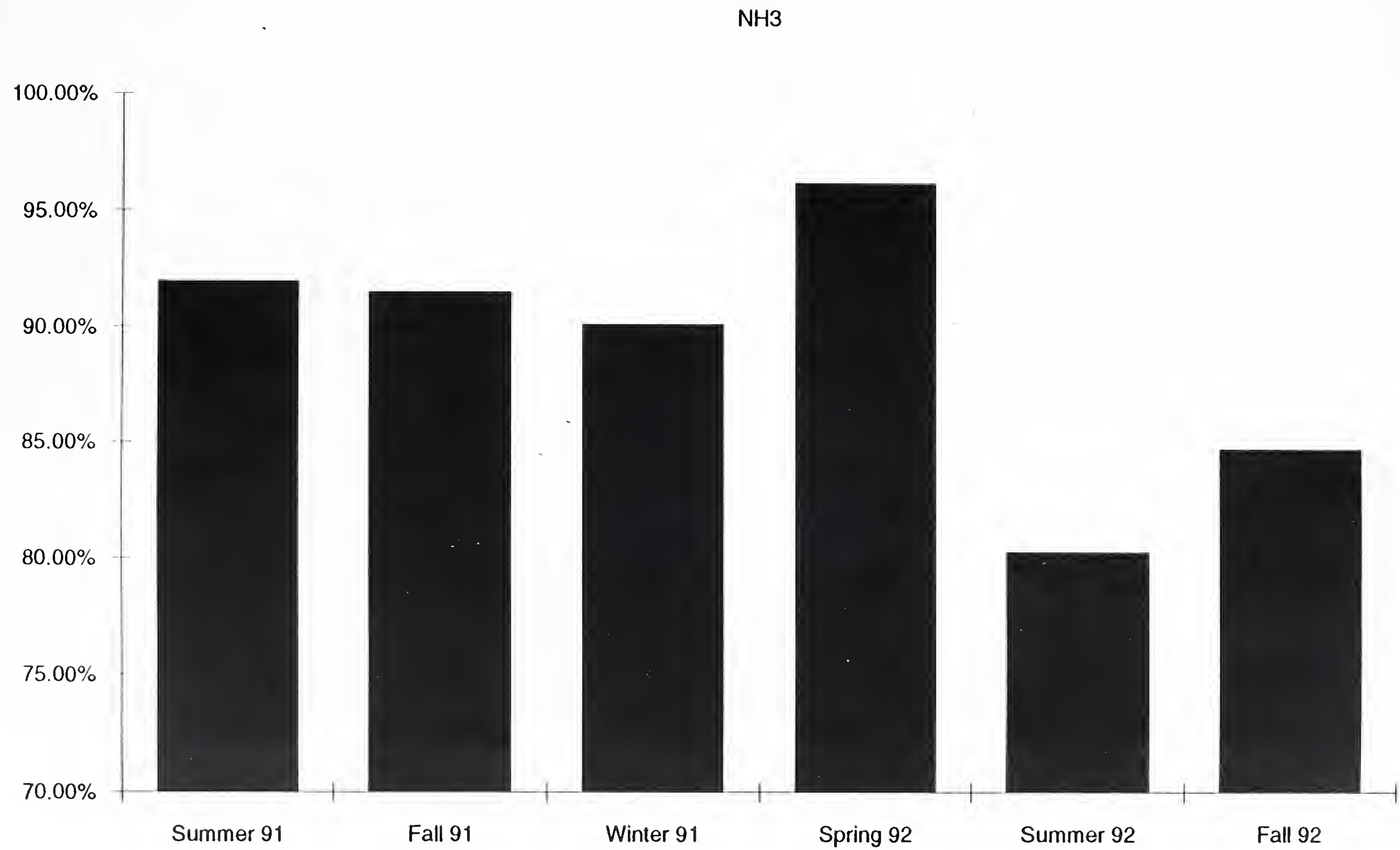

Figure 27. *Mean seasonal reduction of ammonia in wetland cells.*

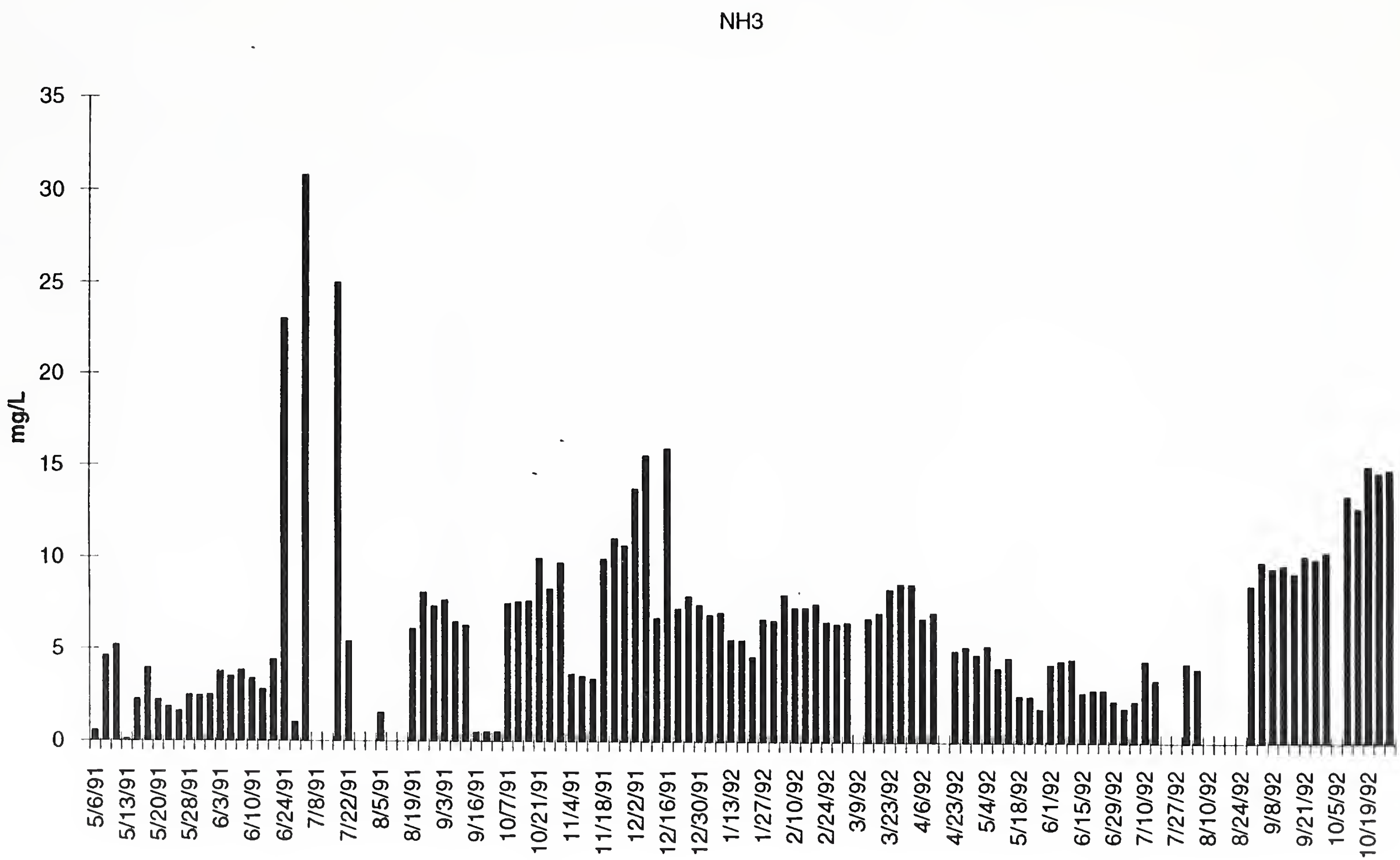

Figure 28. *Inflow station ammonia concentrations during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

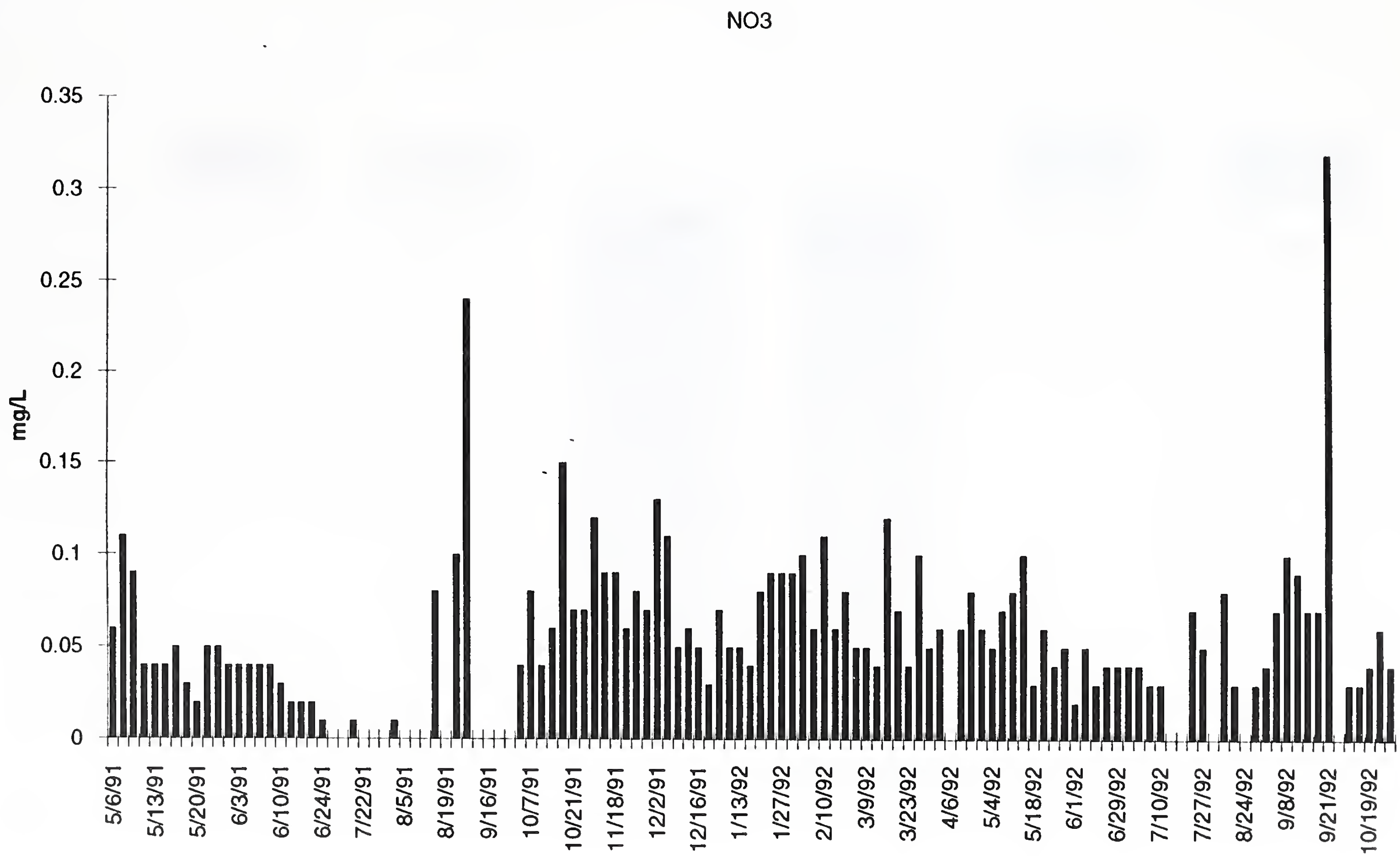

Figure 29. *Inflow station nitrate concentrations during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

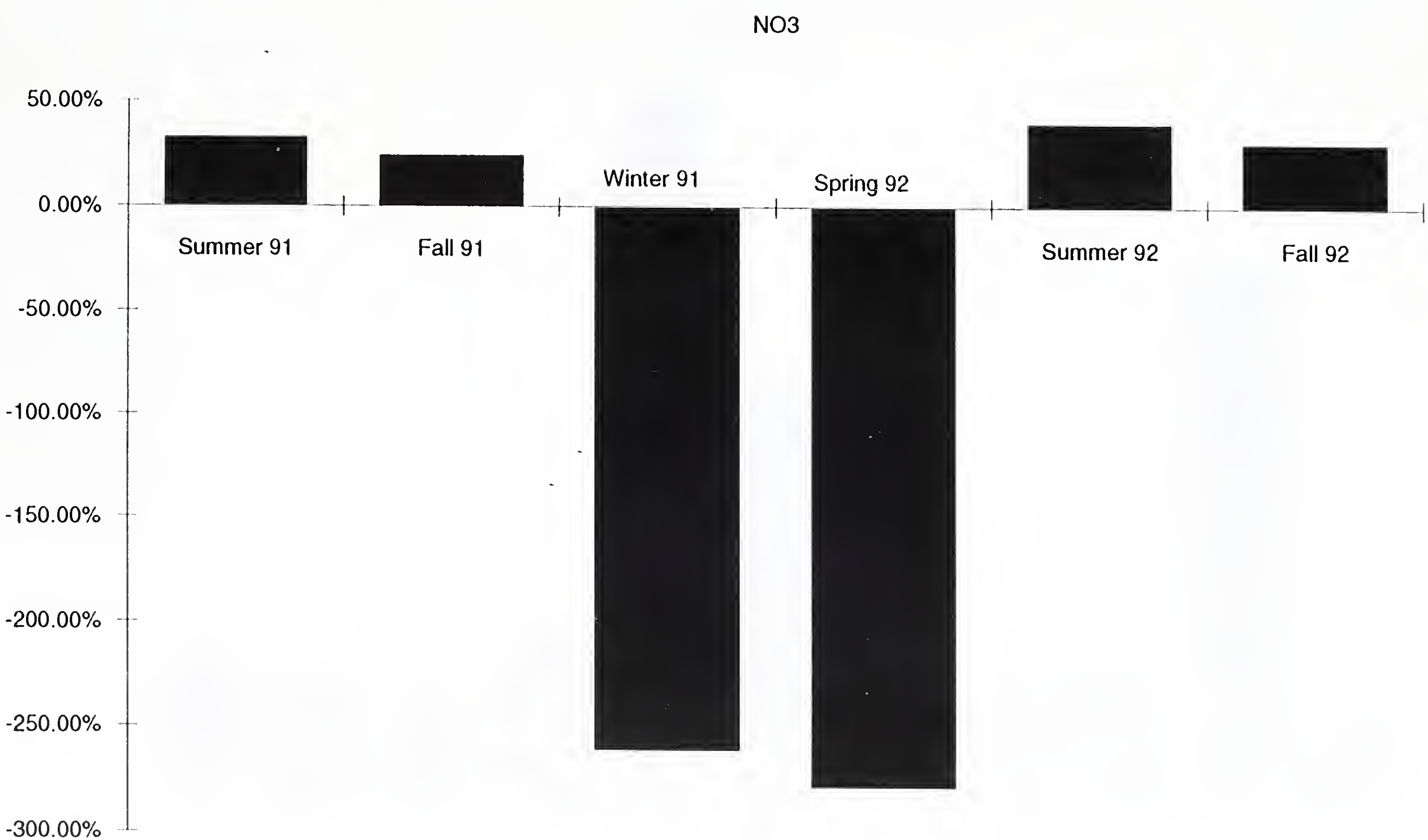

Figure 30. *Mean seasonal reduction of nitrate in wetland cells.*

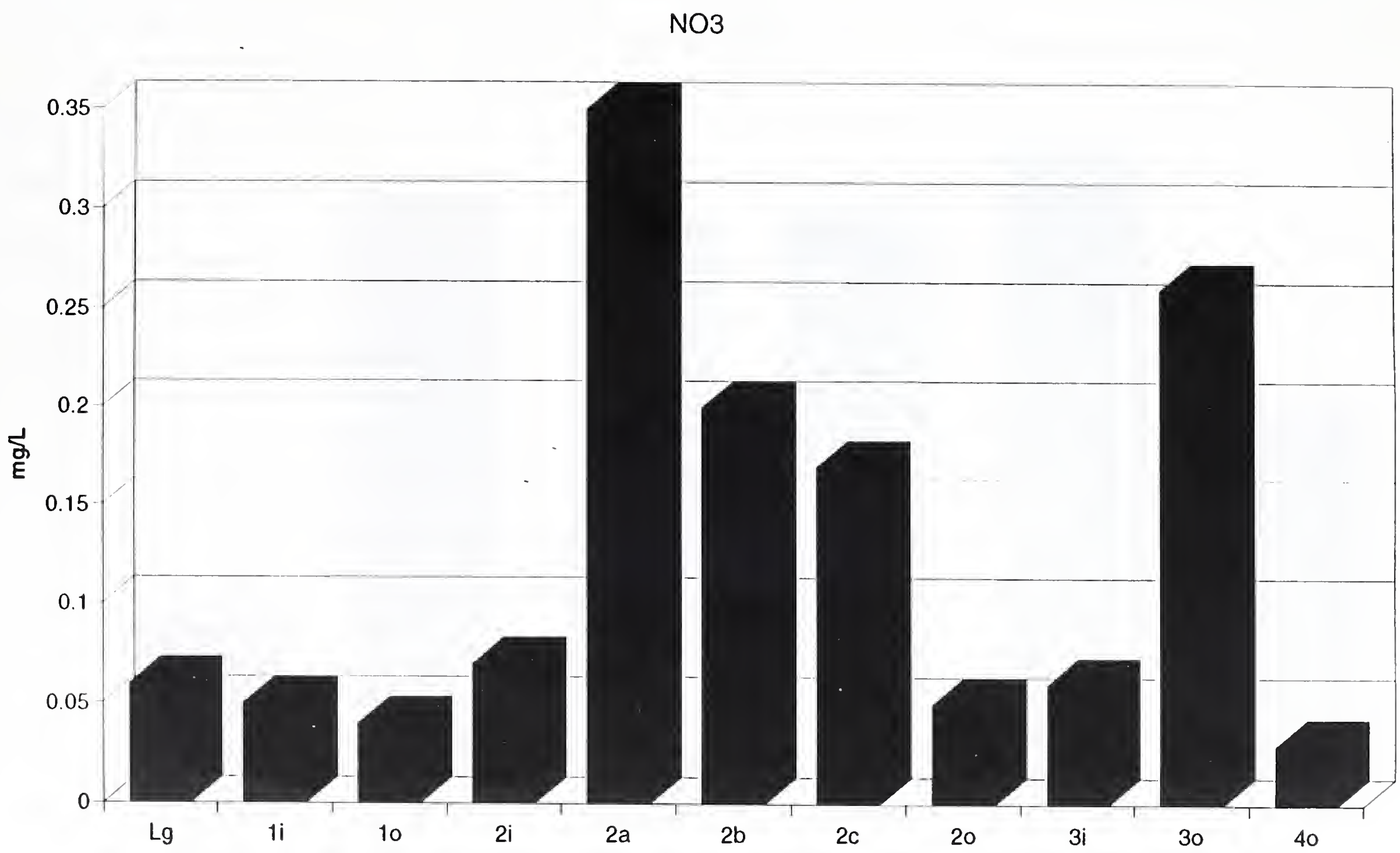

Figure 31. *Mean concentration of nitrate for sampling sites.*

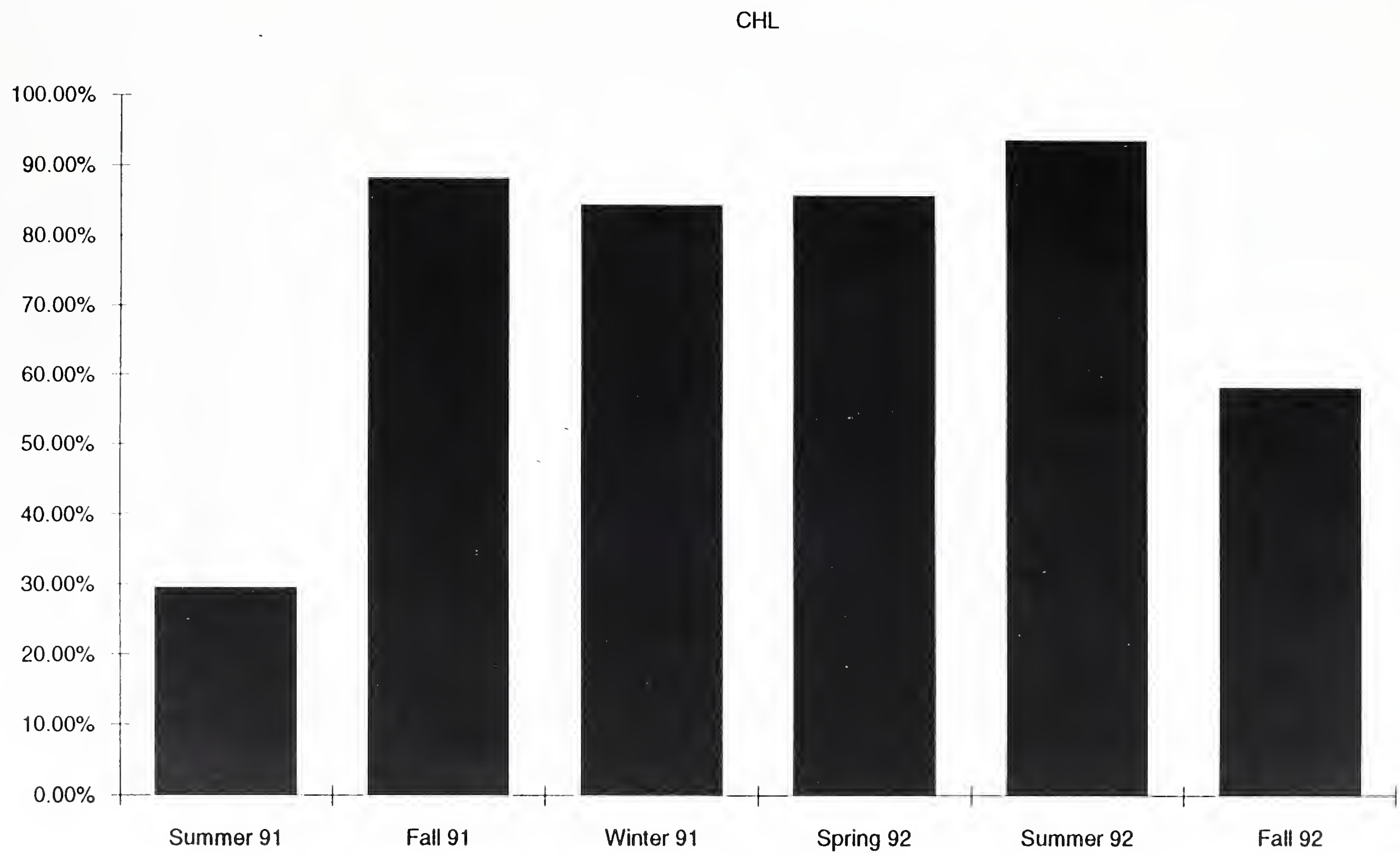

Figure 32. *Mean seasonal reduction of chlorophyll in wetland cells.*

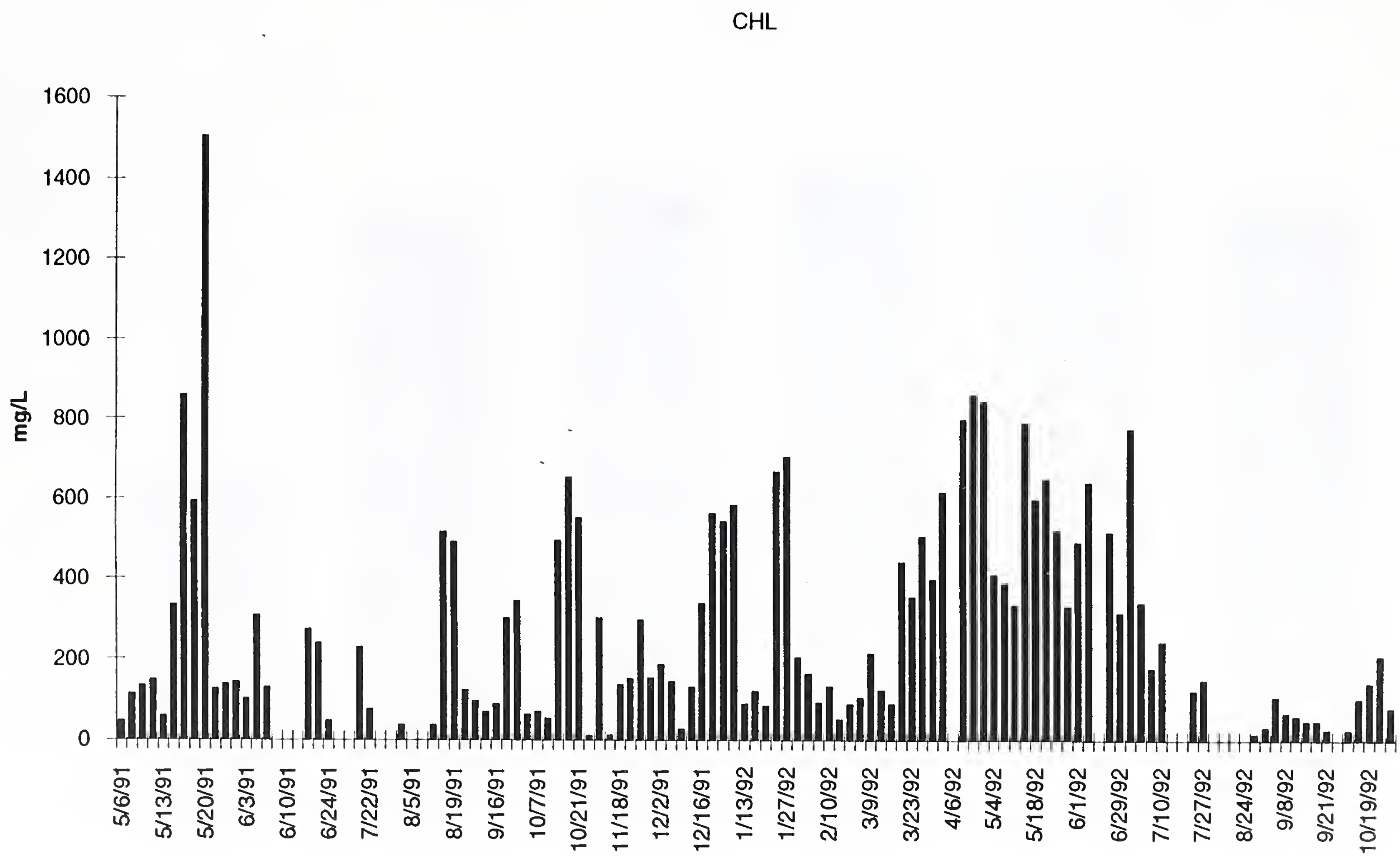

Figure 33. *Inflow station chlorophyll concentrations during the study period.*
(Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)

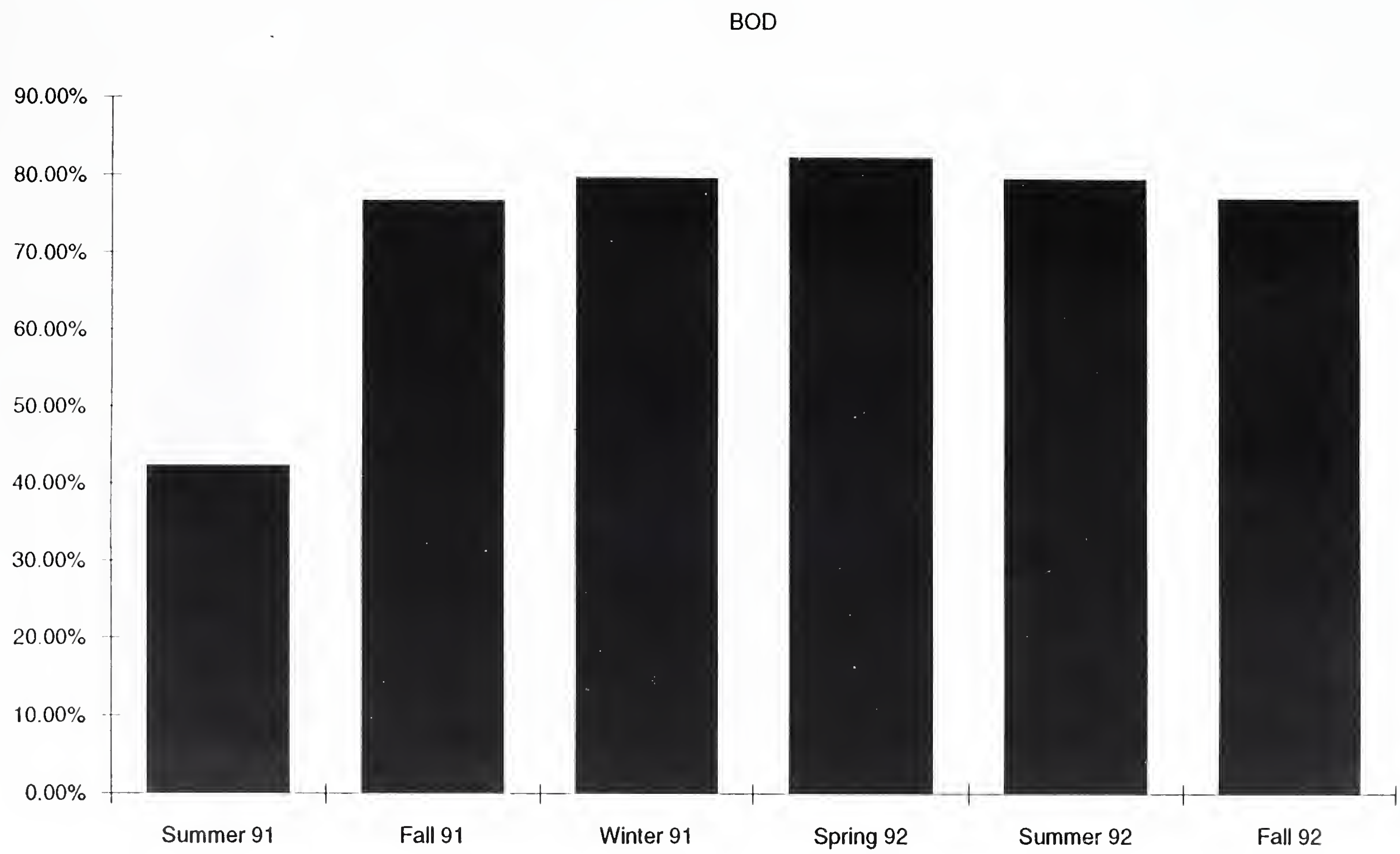

Figure 34. *Mean seasonal reduction of 5-day carbonaceous biochemical oxygen demand in wetland cells.*

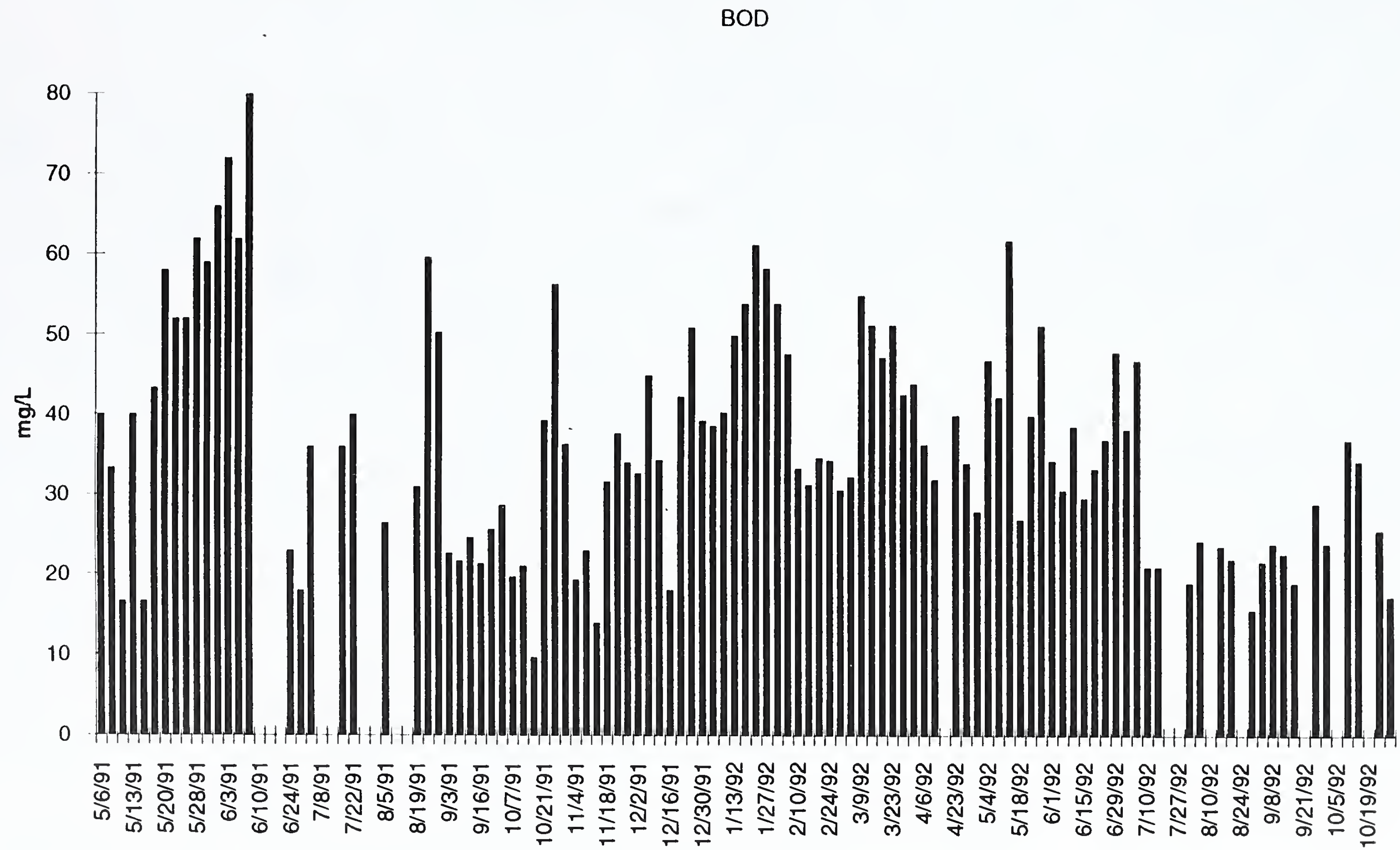

Figure 35. *Inflow station 5-day carbonaceous biochemical oxygen demand values during the study period.* (Each date is represented by all 3 original cell inflows, i.e. 1i, 2i, 3i)